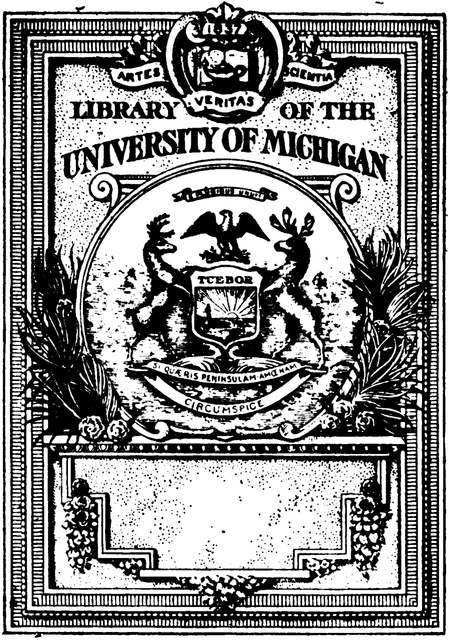
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A TEXT BOOK

OF

ORGANIC CHEMISTRY

BY

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SECOND EDITION, REVISED

NEW YORK
HENRY HOLT AND COMPANY

PREFACE.

An attempt is here made to present the fundamental principles of organic chemistry for the use of those beginning the subject. The most radical departure from the method of treatment adopted in other books treating of the same subject, consists in the dropping of the division into "fatty" and "aromatic" compounds, and in the adoption of what appears to the author a more fundamental and logical classification. This novelty of arrangement will, it is hoped, be found to be justified, partly by the fact that so many connecting links are now known between the two classes of bodies that they no longer stand isolated from each other; and further it is believed that the new method of treatment brings out the important contrasts in chemical conduct for the two series fully as well as the old.

One of the most serious difficulties in presenting this subject lies in the overwhelming and ever increasing mass of material at our disposal. It is no longer possible, within a reasonable compass, to present all classes of compounds even, and important compounds of a given class must often be omitted. No two authors would make the same selection, and that here given is doubtless open to just criticism at some points.

While the amount of material given is very small in comparison with that to be found in large text-books, the reader will find many details which it is impossible for the most conscientious student permanently to retain in his memory. The student is advised, however, to *read* all of the book as well as thoroughly to master, by careful study, some portions of it. The attentive reader will, by this means, gradually absorb many ideas by a process which is closely akin to the acquisition of a language by a child. Only by a combination of the two processes, intensive study of particular topics, and extensive reading in varied fields, can a satisfactory knowledge of any science be acquired.

In study, the student should cultivate especially the habit of connecting all new facts with those which have been previously presented. It is not a series of isolated facts which must be acquired, but a clear grasp of logical relationships. To illustrate: the statement will be found that the ethyl ester of carbostyril is prepared by heating the silver salt with ethyl iodide. The fact in itself is of no consequence; but the thoughtful student should recognize that this is simply an application of one of the general methods previously given for the preparation of esters, and that, in reality, there is no new fact here to be learned, but that, instead, an old fact has been recalled for the purpose of fixing it more firmly in the memory.

By such a process the attentive student gradually acquires, in the study of text-books and by reading the larger literature, the ability to recognize methods which are unusual or striking. This ability, together with the power, which comes later, of recognizing whether a new method is likely to be useful in other cases, is of fundamental importance to all those who wish to pursue the subject beyond its elements. It is partly for this reason that care has been taken, in almost every instance, to give those methods of actual preparation which have been found best for individual compounds. Though, in some few cases, a general method of preparation, or one which throws a clear light on the structure of a compound, has been selected instead of a better practical method which seemed too unusual in its character.

A satisfactory knowledge of organic chemistry cannot be acquired from a text-book or from lectures alone. A large amount of laboratory work is also required. Hints for the direction best given to such work are appended to the individual chapters of the book. These should be carried out with the aid of some of the books on organic work in the laboratory and with reference to the literature. With small classes it is usually best to assign different topics to different individuals and expect each to familiarize himself with the work the others are doing.

In conclusion I wish to express my sincere thanks to Dr. J. Bishop Tingle and to Dr. A. M. Patterson, who have read the book in manuscript and who have offered many valuable suggestions; to President W. E. Stone, who has read the chapter on carbohydrates; to Professor J. H. Long, who has read the chapter on Compounds of Interest in Physiology and Pathology; and to Dr. J. Bishop Tingle and Professor Alexander Smith, who have read the proofs. Thanks are also due to The Chemical Publishing Co., who have kindly permitted the use of several cuts from my "Organic Chemistry for the Laboratory."

PREFACE TO THE SECOND EDITION.

In this edition the chapter on Compounds of Interest in Physiology and Pathology has been rewritten on the basis of the classification of proteïns recently adopted by the American Society of Biological Chemists and the American Physiological Society. I wish to express my thanks to Professor P. B. Hawk for assistance in doing this.

A number of other changes and additions, most of which were prepared for the German edition of the book, have also been included.

URBANA, ILL., March, 1909.

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INTRODUCTION.

In its origin the term *Organic Chemistry* implies a science which discusses the compounds that are found in, or derived from, organized or living bodies. There was, at one time, a general opinion that such compounds differed in some manner from others, and that they resulted from the action of some occult vital force. As many of these bodies have been prepared from the elements by pure laboratory processes, such a view has long since become untenable, and no one now supposes that the chemical forces within the living plant or animal differ in any respect from those outside. A very large proportion, too, of the eighty thousand or more compounds known to the science have never been found in plants or animals. The name is retained in spite of these objections, partly because it is convenient from long, well-established usage, partly because animal and vegetable substances still remain the practical source of most of those carbon compounds with which the student of organic chemistry is concerned.

The natural source of the carbon compounds is the carbon dioxide of the atmosphere. This is absorbed by plants, and the compounds required for vegetable growth are produced by a process of reduction, accompanied by the evolution of free oxygen, and a combination of the carbon with the elements of water. The energy absorbed in the process is very considerable, and this is furnished by the sunlight. There seems to be some microscopic evidence that starch is one of the first products formed by the assimilation of the carbon; and there is also good ground for the belief that the chlorophyl of the leaf is directly active in the process, but positive knowledge with regard to the chemical phenomena involved is very meager.

The bodies which appear to be most closely connected with the phenomena of life, both in plants and in animals, are the proteïns, compounds containing carbon, hydrogen, oxygen, nitrogen, and sulphur. But the knowledge of the chemistry of these bodies, to say nothing of the part which they undoubtedly play in the syntheses occurring within living bodies, is, at present, very unsatisfactory. This is owing to their extremely complex nature, and to the fact that very few of them can be crystallized, making it impossible to judge satisfactorily of the homogeneous nature, and so of the purity, of any one of them when prepared.

The nitrogen of the proteïns is furnished to the plant partly by the nitrates and other nitrogenous compounds of the soil, and partly by the nitrogen of the air, which may, in some cases, be assimilated by the plant with the aid of micro-organisms which attach themselves to its roots.

A great variety of compounds are formed in plants besides starch, cellulose, or woody fiber, and proteïns. The most important classes of these compounds are the gums, sugars, fats or oils, acids and esters, all of which contain carbon, hydrogen, and oxygen; the glucosides, which sometimes contain nitrogen in addition; the alkaloids containing carbon, hydrogen, and nitrogen, and frequently oxygen; and the terpenes and volatile ("essential") oils, which are mostly compounds of carbon and hydrogen, though the latter sometimes contain oxygen.

Chlorine, sulphur, phosphorus, silicon, sodium, magnesium, potassium, calcium, and iron are taken up from the soil, and are essential to the life and growth of most plants. The basic elements are found, in some cases, as a part of the salts of organic acids; otherwise the nature of the compounds which these elements form and the part which they play in the plant growth is, with few exceptions, wholly undetermined.

Animals must secure the carbon compounds required for their life and growth directly or indirectly from the substances furnished by plants. In general the characteristic processes of plant life are reduction processes accompanied by an evolution of oxygen; those of animal life, on the other hand, oxidation processes resulting in an evolution of carbon dioxide and the formation of urea, which may be considered as a compound of carbon dioxide with ammonia, less the elements of water. The plant growth, too, is mainly a synthetical process, accompanied by an absorption of energy; animal life, a process associated with a decomposition of complex compounds into simpler ones, and accompanied by an evolution of heat and mechanical energy. But while this is true in general outline, oxidation and evolution of carbon dioxide may take place in the plant, notably in the blossom and during the night; and many synthetical processes occur in animal bodies.

Under the influence of bacteria there are formed during processes of putrefaction, and also in connection with many forms of disease, basic compounds called ptomaines. These contain carbon, hydrogen, and nitrogen, and, frequently, oxygen. Other violently poisonous compounds, known as toxalbumins from their supposed relation to the proteïns, or albuminous bodies,* are also formed in a similar manner.

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* **Professor Vaughn, however, considers that these compounds are not albumins, and designates them by the more general name toxins.**

The life processes which have been sketched in the barest outline furnish the practical materials with which the science of organic chemistry has to deal. The problems with which it is concerned are: first, the separation of individual compounds in a pure state, followed by their analysis and a determination of their molecular weights; and, second, the study of the relations existing between these compounds, and the study of the compounds which may be prepared from them. As has already been stated, the derivatives now far exceed in number those compounds which have been obtained directly from living bodies.

Structural Formulae. — Many of the relations existing among the carbon compounds find their most concise expression in structural formulae. The principles which lie at the foundation of these formulae are:

1. That a given atom in a compound is *directly* united to only a small number of other atoms, and that for each element this number never exceeds a certain amount which is known as the highest valence of the element. For carbon this highest valence is four. Whether the combination of atoms consists in their actual attachment to each other, or whether they are held by their mutual attractions in a state of vibration between narrow limits about points of stable equilibrium, or whether they are held in definite positions with regard to each other by the effect of their motions on the ether, and through that upon each other, are at present matters of scarcely more than mere speculation. With such questions structural formulae have, at present, practically nothing to do.

2. That in many reactions a group of atoms from one molecule becomes a part of a new molecule without any structural change within the group. Thus, in the transformation

of acetic acid, $C_2H_4O_2$, into acetyl chloride, C_2H_3OCl, the carbon, hydrogen, and oxygen atoms of the acetyl group, C_2H_3O, are supposed not only to hold together in passing from one compound to the other, but it is also supposed that they retain their order of structural arrangement; that, for instance, a hydrogen atom which is attached to a given carbon atom in acetic acid is attached to the same carbon atom in acetyl chloride. It does not follow from this that the mutual relations between the atoms within the group may not be greatly altered by the passage of the group from one compound to another. Thus a hydrogen atom in acetyl chloride may be more or less easily affected by some reagents than the same hydrogen atom in acetic acid. In many cases differences of this sort are very marked. We are not even compelled to suppose that there is a set geometrical form which is retained by the group in the various compounds into which it enters. But an intelligent discussion of the facts of organic chemistry is not at present possible without the assumption of that maintenance of structural arrangement, *or order of attachment*, within groups which is here stated.

Groups of the kind here described are called radicals.

3. It is usually assumed that when an atom or group leaves a compound and another atom or group enters it, the latter attaches itself at the point left vacant by the former. This principle is, in an important sense, merely a corollary of that last stated.

In practically applying these principles for the determination of the structure, or order of arrangement, of a given compound, two general methods may be used: the analytical method, which consists in breaking the compound down and identifying the various groups which it contains; and the synthetical method, which consists in building up the compound by putting together known groups. The second method is usually more satisfactory and conclusive.

From the nature of the case, it often happens that the structure of a given group does not remain unchanged when it enters a new compound, and in such cases the results obtained in different reactions may be contradictory; and it may be necessary to accumulate a large amount of evidence before a satisfactory conclusion can be reached.

Classification. — In classifying the material of organic chemistry for the use of beginners in the science, a fundamental difficulty is met. It is especially true in this science that no single compound can be understood without a knowledge of a considerable number of other compounds, and the relation to other compounds is usually the most important part of the knowledge which must be acquired. It is frequently necessary at the outset, therefore, to refer to compounds not previously described.

The hydrocarbons are usually selected for first consideration because of the fundamental relation which they bear to all other compounds. One treatise on organic chemistry, indeed, calls the science that of *the hydrocarbons and their derivatives.* In the further classification it has been customary to divide organic compounds into two groups, the *aliphatic* or fatty acid compounds, and the *aromatic* compounds, or benzene and its derivatives.

One of the best of the larger text-books * adopts the following closely related classification :

1. *Aliphatic*, or open chain compounds.
2. *Isocyclic* compounds, containing rings of carbon atoms.
3. *Heterocyclic* compounds, containing rings composed of atoms of two or more kinds, as carbon and nitrogen, carbon and sulphur, etc.

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* Lehrbuch der Organischen Chemie, von Meyer und Jacobson.

The distinction between aliphatic and aromatic compounds has lost something of its force of later years, and an attempt has been made in the present work to return to a simpler and more logical classification. The hydrocarbons are considered first, as heretofore, and all classes of them together. Then follow oxygen compounds and compounds containing halogens, nitrogen, and sulphur, and, finally, three chapters upon heterocyclic compounds, alkaloids, and compounds of physiological and pathological interest.

ORGANIC CHEMISTRY.

CHAPTER I.

PURIFICATION, ANALYSIS, DETERMINATION OF MOLECULAR WEIGHTS, AND FORMULAE.

THE practical basis on which organic chemistry rests is the preparation and separation of homogeneous, or, as commonly stated, pure substances, and the determination of their physical and chemical properties.

Purification. — The most important general means used for separation and purification are, treatment with solvents, crystallization, and distillation. The solvents most frequently used are water, alcohol, ether, ligroin or gasoline, chloroform, carbon bisulphide, benzene, glacial acetic acid, formic acid, amyl alcohol, acetic ether, acetone, and nitrobenzene. It is noticeable that all of these except water are carbon compounds. Alcohol is, perhaps, the most generally applicable.

Crystallization may be effected by the cooling of liquid substances, in which case the portion that does not solidify is sucked away, removed by appropriate solvents, or absorbed by spreading the solid substance on porous porcelain; or, from solution, by cooling hot solutions tion or

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Crystallization may be effected by the cooling of liquid substances, in which case the portion that does not solidify is sucked away, removed by appropriate solvents, or absorbed by spreading the solid substance on porous porcelain; or, from solution, by cooling hot solutions, by evaporation or by dilution, — as, for instance, alcohol with water or ether with benzene. It is generally true that in the formation of crystals, molecules of the same kind tend to unite to form larger aggregates, and, in so doing, exclude molecules of a different kind. This tendency is not, however, universal, and isomorphous substances cannot be separated by crystallization.

Crystalline Form. — The form assumed in crystallization is one of the most important characteristics of chemical compounds, and for the purpose of establishing the identity or non-identity of two substances the determination of the exact crystalline form by measuring the angles between the faces of the crystals has been found very important. The *melting point* of crystalline * substances is also a very definite and useful characteristic. When a sufficient amount of the substance is available, this is best determined by melting it in a test-tube or beaker and allowing it to cool slowly till it solidifies, stirring constantly with a thermometer. The temperature remains constant for a time at the melting point. It is frequently necessary to start the solidification by the addition of a fragment of the solid because of the phenomena of "overcooling." (See Ostwald, *Zeit. f. phys. Ch.* **22**, 289.)

For practical purposes, the determination of the melting point with the use of a minute quantity of the substance is usually sufficient. For this purpose a glass tube 4 or 5 mm. in external diameter is drawn out to form alternate bulbs and capillary tubes as shown in Fig. 1. The narrow portion is about 1 mm. in diameter, the tubes are sealed off near each bulb, and for use the bulbs are broken in two, after scratching with a file. The finely

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* Amorphous substances do not, usually, have a definite melting point.

powdered dry substance is put into the tube and shaken to the bottom. The tube is then attached to the thermometer by means of a platinum wire (Fig. 2), and heated slowly in a bath of concentrated sulphuric acid, in a 75 cc. round bottomed flask, or, for substances melting above 280°, in a beaker containing paraffin. A greater accuracy than about 0.5° is not to be expected by this method.

Fig. 1.

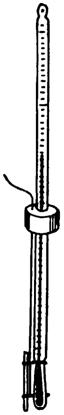

Fig. 2.

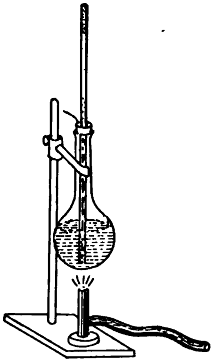

Fig. 3.

Correction for Thermometer. — If the stem of the thermometer is not immersed to the point of reading, the following correction must be added:

$N(t-t')$ 0.000154.

N = number of degrees on that part of the stem of the thermometer outside the bath.

t = temperature read.

t' = average temperature of stem.

0.000154 = coefficient of apparent expansion of mercury in glass.

Impure substances, when, as is usually the case, the impurity dissolves in the melted substance, melt at a lower temperature than pure ones. Also, since the concentration of the solution of the impurity in the melted substance will usually decrease as more of the latter becomes liquid, impure substances will often show a range of several degrees between the beginning and end of melting. For the same reason the point of complete liquefaction is likely to be nearer to the true melting point than the point at which melting begins. A greater range than 1° between the two points is always to be regarded with suspicion, for substances which do not decompose on melting.

Very few general statements can be made about the melting points of organic compounds. In general, the experienced chemist knows that compounds of certain classes are usually liquids while those of other classes are solids at ordinary temperature, but there are so many exceptions that few general statements can be made. Perhaps the most important general statement of this sort is that, in a given class of substances, compounds of symmetrical structure are likely to have a higher melting point than others which are less symmetrical.

Distillation. — After crystallization, the most important means for obtaining pure substances is by distillation. Mixtures usually have a different boiling point from that of their constituents. Since, in general, the boiling point of a mixture rises from the beginning to the end of its distillation, and this rise in the boiling point must correspond to a change in the composition of the mixture, it follows that, by collecting the distillate in several portions, and subjecting these portions to repeated distillation, a more or less complete separation of the constituents can be effected. Such a process is called *fractional distillation.*

Fractional Distillation. — The solution of a non-volatile substance in a volatile one causes a lowering of the vapor pressure and so a rise in the boiling point of the solvent (see p. 34). If both substances are volatile, the vapor pressures of the two are added, but at the same time each substance tends to cause a lowering of the vapor pressure of the other. According as one or the other of these factors produces a greater effect the boiling point may be higher or lower than that of either constituent. We may distinguish, therefore, the following practical cases in the application of fractional distillation to the separation of two substances:

I. *The boiling point of all mixtures is higher than that of the lower boiling constituent and lower than that of the higher boiling one.* In such a case a practically complete separation of the two constituents can be effected by repeated fractionation. Ethyl alcohol and water are usually given as an illustration of this case, but, for the reasons given below it is apparent that the mixture really belongs under II. It would seem that in the majority of cases mixtures of organic liquids either fall under this case, or that the minimum boiling point is reached for a mixture containing so small a percentage of the higher boiling constituent that the compound with lower boiling point can be obtained in a practically pure condition.

II. *The addition of a small amount of either substance lowers the boiling point of the other.* Since from a mixture of ethyl alcohol and water containing but one per cent of water the portion distilling first contains more water than that which distills later, and since from mixtures containing only a small per cent of alcohol, the alcohol is all found in the earlier portions of the distillate, a mixture of the two substances must come under this head. From a dilute alcohol the mixture may be concentrated by fractioning till an alcohol of 96 per cent is obtained. This concentration corresponds to the minimum boiling point and maximum vapor pressure which can be obtained for any mixture of alcohol and water. (*J. Am. Chem. Soc.*, **23**, 463.)

III. *The addition of a small amount of either substance raises the boiling point of the other.* If water is added to formic acid or if formic acid is added to water, the boiling point of either is raised and the vapor pressure is lowered till a mixture containing 77.5 per cent of formic acid and boiling at 107.1° is reached. In such cases the concentration corresponding to the maximum boiling point varies somewhat with the pressure. (Roscoe, *Ann. d. Chem.* (Liebig) **125**, 320.) Substances which undergo considerable ionization in aqueous solution appear to afford the most marked illustrations of this case.

IV. *Addition of the higher boiling substance lowers the boiling point of the lower boiling substance, and addition of the lower boiling substance raises the boiling point of the higher boiling substance. This case has not, apparently, been met in practice.*

The accompanying diagram will be of service in gaining a clear conception of the phenomena discussed. The ordinates represent boiling points, while the abscissæ represent percentages of the substance whose boiling point is found where the curve cuts the ordinate at the extreme right.

The student will find it to his advantage to answer, with the aid of the diagram, the following questions:

By continued fractioning, how far can the following mixtures be separated: 25 per cent alcohol? 99 per cent alcohol? 50 per cent formic acid? 90 per cent formic acid?

To which cases do solutions of hydrochloric acid and of ammonia belong?

An inspection of the boiling point curve will usually indicate the ease or difficulty with which two substances can be separated by fractional distillation. Thus, for ethyl alcohol and water, a glance at the curve shows that water may be easily separated from a small amount of alcohol and that the concentration of the alcohol to forty or fifty per cent may be easily effected, but that beyond this point the further concentration is increasingly difficult. In such cases, separation by means of repeated distillation with a flask or plain distilling bulb and condenser (Fig. 4) often becomes very tedious. The rate of separation can be greatly hastened by the use of various forms of apparatus which have been devised to secure a continuous fractional condensation

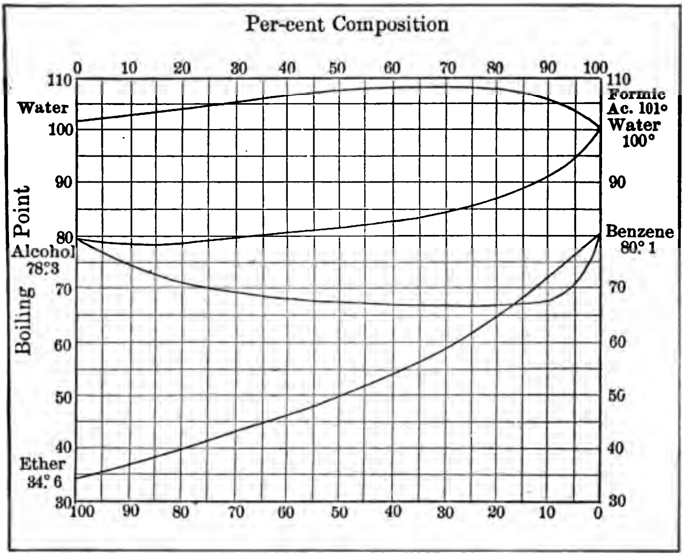

Fig. 3a.

during the process of distillation. The most efficient apparatus of this sort is that used in the distillation of ethyl alcohol (p. 131). Of the forms of laboratory apparatus used for the same purpose, Ladenburg's distilling bulb (Fig. 5) and Hempel's column of glass beads (Fig. 6) may be mentioned.

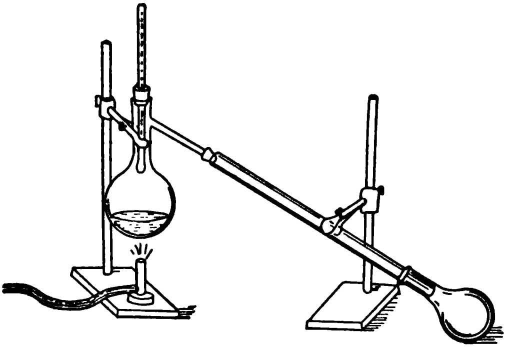

Fig. 4.

Distillation Under Diminished Pressure. — Many substances cannot be distilled in the ordinary manner because they decompose at a temperature below their boiling point. Some of these can be successfully distilled if the boiling point is lowered by reducing the pressure. A reduction of the pressure to 30 mm. will usually cause a lowering of the boiling point by about 100°; the amount being generally greater for high boiling than for low boiling substances. (See G. W. A. Kahlbaum, *Zeit. phys. Chem.* **26**, 577.) A fur-

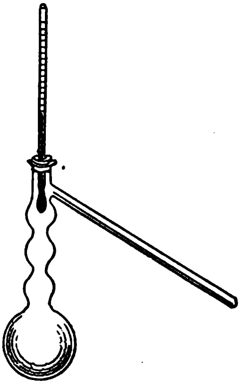

Fig. 5.

ther reduction of the pressure causes an additional rapid lowering of the boiling point, so that some substances may be distilled with advantage under the low pressures which can be obtained with a mercury pump. (Krafft, *Ber. d. chem. Ges.* 28, 2583; 29, 1316, 2240.) For most purposes, however, the pressure is reduced by means of a good filter pump, and the simple apparatus shown in Fig. 7 can be used. The tube by the side of the thermometer is drawn out to a very fine capillary, and reaches to the bottom of the bulb to introduce a rapid stream of small bubbles of air. This prevents overheating and bumping of the liquid, which are, otherwise, very troublesome. The bulb is usually heated in an oil bath.

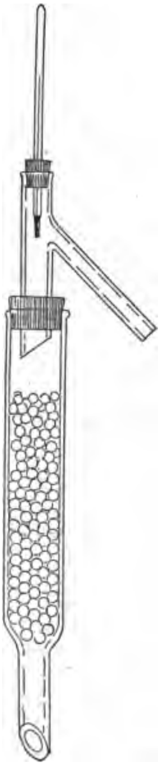

Fig. 6.

Steam Distillation. — Distillation in a current of steam is closely related, in principle, to distillation under diminished pressure. Substances which boil below 250°–300° have a sufficiently high vapor pressure at 100°, so that, if they are kept at that temperature in a constantly changing atmosphere, they will slowly evaporate. If steam is used to furnish the changing atmosphere, they will, of course, condense again along with the steam (Fig. 8). The rates of distillation will vary directly as the vapor pressure and directly as the molecular weight. (Why?) It must be remembered, however, that the ionization caused by the water, or the presence of other high boiling substances, will often seriously lower the vapor pressure of the substance distilled.

is inserted to reduce the oxides of nitrogen formed. If sulphur or halogens are present, lead chromate or silver foil must be used to retain them. The water formed is absorbed

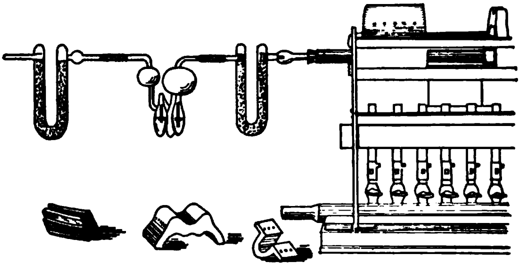

Fig. 9.

in a tube containing calcium chloride, or concentrated sulphuric acid, the carbon dioxide, in bulbs containing a strong solution of potassium hydroxide and having attached a small tube filled with solid caustic potash to retain moisture (Fig. 9).

Nitrogen. — Three methods are in general use for the determination of *nitrogen*. The *absolute method*, which is universally applicable, consists in burning the substance with copper oxide either in the vacuum produced by a Sprengel pump, or in an atmosphere of carbon dioxide, and in measuring the nitrogen, after the absorption of the carbon dioxide. The *soda-lime method*, which is more limited in its applications, but which is accurate for amines, amides, and a large proportion of the natural organic compounds, consists in burning the substance by heating it with a mixture of slaked lime and sodium hydroxide or sodium carbonate (Johnson, *Am. Chem. J.*, 1, 77). The nitrogen is converted into ammonia. and the latter is absorbed in a measured quantity of standard acid. The *Kjeldahl method*, which, in some of its forms, is almost universally applicable, consists in heating the substance with concentrated sulphuric acid and potassium sulphate, copper sulphate or other substances, according to its nature.

Halogens and Sulphur. — The *halogens* are determined by use of quicklime, or of fuming nitric acid as outlined above under qualitative examination. *Sulphur* is determined as barium sulphate after oxidation with fuming nitric acid in a sealed tube (Carius), or with potassium hydroxide and potassium nitrate in a silver crucible (Liebig). *Oxygen* is almost invariably determined by subtracting the percentages of other constituents from 100.

PROBLEM. — 0.1938 gram of a substance gave 0.2600 g. CO_2 and 0.0750 g. H_2O. 0.2548 gram of the same substance gave 55.9 cc. N at 13° and 746 mm. What is the percentage composition of the substance?

Empirical Formulae. — After the percentage composition of a substance has been determined, the simplest empirical formula can be deduced by an application of the following principle: The amount of each element present must be proportional to the product of the atomic weight of the element multiplied by the number of its atoms in one molecule of the compound. Thus for sodium acetate, $NaC_2H_3O_2$, the percentages of sodium, carbon, hydrogen, and oxygen in the compound must be in the same ratio to each other as the numbers 23 : 24 : 3 : 32. If the percentage of each element is divided by the atomic weight of the element, the resulting quotients must be proportional simply to the number of atoms for each element. Thus, for sodium acetate:

Sodium	28.05	Per cent	$\div 23 = 1.22$
Carbon	29.27	"	$\div 12 = 2.44$
Hydrogen	3.66	"	$\div 1 = 3.66$
Oxygen	39.02	"	$\div 16 = 2.44$

In this case a mere inspection of the quotients shows them to be in the ratio 1 : 2 : 3 : 2, and the simplest empirical formula, $NaC_2H_3O_2$, follows at once. Sometimes the simplest ratio corresponding to the quotients is not so easily perceived and, in such a case, each quotient may be divided again by the smallest of the quotients. From the new quotients it is usually easy to derive the formula. After the formula has been found it is best to confirm it by calculating from it the theoretical percentage composition and comparing this with the results found by analysis. An exact agreement is not, of course, to be expected, but the limits of the differences which should arise from errors of analysis are pretty well understood. Usually carbon determinations come out a little too low, hydrogen determinations too high, and nitrogen determinations, by the absolute method, too high.

What is the simplest formula for the substance whose analysis is given on p. 21?

Determination of Molecular Weight. — Analysis alone will not decide between an empirical formula and any multiple of that formula. The percentage composition of a compound of the formula $Na_2C_4H_6O_4$ would be exactly the same as that of sodium acetate, $NaC_2H_3O_2$. The decision between formulae which are related to each other in this way must be made by means of a determination of the molecular weight. The methods most often used for this purpose are, a determination of the vapor density, a determination of the lowering of the freezing point, or of the vapor pressure, or the raising of the boiling point of some compound when a known weight of the substance is dissolved in it, or a determination of the composition of some simple derivative, especially of some substitution product.

Determination of the Vapor Density. — One gram-molecule (32 grams) of oxygen occupies, at 0° and 760 mm., 22.39 liters $\left(=\frac{32}{1.429}\right)$. In accordance with Avogadro's hypothesis the same "normal volume" of any other gas under standard conditions must also contain one gram molecule of that gas. In other words, if we determine the weight in grams of 22.39 liters of any gaseous substance under standard conditions, the result must also express its molecular weight.

The determination may be made either by weighing a known volume of the vapor or by measuring the volume of a known weight of the vapor.

Dumas' Method. — In Dumas' method a light glass bulb, having a capacity of 100–200 cc. and with the neck drawn out to a fine tube, is carefully weighed and a moderate quantity of the substance to be examined (6–10 grams) is introduced. The bulb is then placed in an apparatus where it can be surrounded with live steam, or, in the case of high boiling liquids, in an oil bath or some arrangement for heating the bulb to some constant tempera-

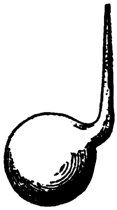

Fig. 10.

Fig. 11.

ture which is at least 20°–30° above the boiling point of the substance. The temperature must, of course, be noted. As the substance boils it expels the air in the bulb, leaving the latter full of the vapor. The end of the vaporization can be easily determined by burning the vapors as they escape. The tube is then sealed with a small flame and the bulb is cooled, cleaned, and weighed. The gain in weight plus the weight of air which the bulb would contain at the temperature and pressure of the second weighing, gives the weight of the vapor. The volume of the bulb is determined by breaking off the tip under water, and weighing the bulb again after it is filled. The calculations are most easily made by reducing the volume of the air from the temperature and pressure of the second weighing of the bulb, and that of the vapor from the temperature and pressure at the sealing of the bulb, to the volume which they would occupy at 0° and 760 mm. The weight of a cubic centimeter of air may be taken as 0.001293 grams.

PROBLEM. — What is the weight of the normal volume and the molecular weight of a substance which gave the following data?

Weight of bulb full of air	60.2572 grams.
" " " " " vapor	60.7122 grams.
Temperature at sealing	150°.
Barometric pressure	740 mm.
Temperature at second weighing . .	22°.
Weight of bulb full of water	170.26 grams.

Determinations of molecular weight are usually made to decide between quantities which are quite widely different, and a high degree of accuracy is not required. Corrections for the expansion of the glass and for the deviation of the weight of a cubic centimeter of water from one gram are unnecessary. As the deviation of a vapor from the condition of a theoretically perfect gas is in the direction of greater density, the tendency is toward high results.

Victor Meyer's Method. — Dumas' method requires a relatively large amount of material, and the presence of a small amount of some higher boiling impurity may cause a considerable error. For these reasons, and because of its great simplicity, the air displacement method of V. Meyer has come into almost exclusive practical use. A bulb having a capacity of about 200 cc., and having attached to it a long tube, with a side tube near the top, is heated to a constant temperature by the vapor of some substance[*] (Fig. 12). When air no longer escapes from the side tube a eudiometer filled with water is placed over the latter and the substance, previously weighed in a small bottle or bulb, is introduced by raising the stopper for a moment, and instantly replacing it after dropping the bottle in, or, better, by means of the dropping arrangement shown in Fig. 13. A little glass wool is put in the bottom of the bulb to prevent its being broken by the fall of the bottle. The substance soon vaporizes, and

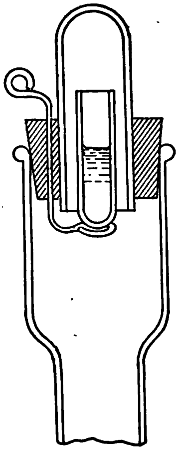

Fig. 13.

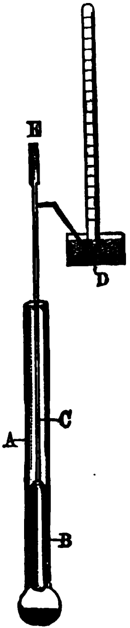

Fig. 12.

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[*] Toluene, 111°, xylene, 140°, naphthalene, 218°, diphenylamine, 310°, sulphur, 448°, phosphorus pentasulphide, 530°, or other substances, may be used according to the boiling point of the substance under examination.

the vapor expels its own volume of air, which is collected in the eudiometer and measured. Since the volume of the latter depends on the temperature at which it is measured, and not on the temperature at which vaporization takes place, the exact temperature of the bulb is unimportant. This has rendered the method useful for inorganic substances at very high temperatures as well as for common laboratory use for organic compounds.

PROBLEM.—Calculate what molecular weight corresponds to the following results:

Weight of substance	0.0550 gram.
Volume of air	18.3 cc.
Temperature	20°.
Barometric pressure	745 mm.
Aqueous vapor pressure (from table) .	17.4 mm.

Hofmann's Method (*Ber. d. chem. Ges.* 1, 198) is especially useful for substances which decompose at their boiling point or slightly above. The substance is introduced into a barometer tube filled with mercury and surrounded with a jacket through which steam, or the vapor of aniline or some other substance, is passed. By this means the substance is vaporized under diminished pressure.

DETERMINATION OF MOLECULAR WEIGHTS BY THE LOWERING OF THE FREEZING POINT OF A SOLUTION.

It has been found that by precipitating copper ferrocyanide in the walls of a cylinder of porous porcelain, a gelatinous membrane is formed that will allow water to pass slowly through, but which is impervious to sugar and similar substances that are dissolved in the water. If a solution of sugar is placed within such a cylinder and the cylinder is closed with a stopper bearing a small bent glass tube, closed at the end, and partly filled with mercury and partly with air, and the whole is placed in a vessel containing pure water, water will enter through the semipermeable membrane until a very considerable pressure is developed within the cylinder. This pressure is known as osmotic pressure, and can be measured by the decrease in the volume of air in the bent tube (Fig. 14). When this pressure has reached its maximum, it is approximately equal to the pressure which would be exerted if the substance in solution occupied the same space in the form of a gas at the same temperature. Now, if the weight, volume, pressure, and temperature of a gas are known, the molecular weight is easily calculated. The determination of the osmotic pressure of a solution of known concentration would, therefore, furnish the same means for the determination of the molecular weight of a substance as the determination of its vapor density. Such a method is especially desirable because many substances cannot be vaporized without decomposition.

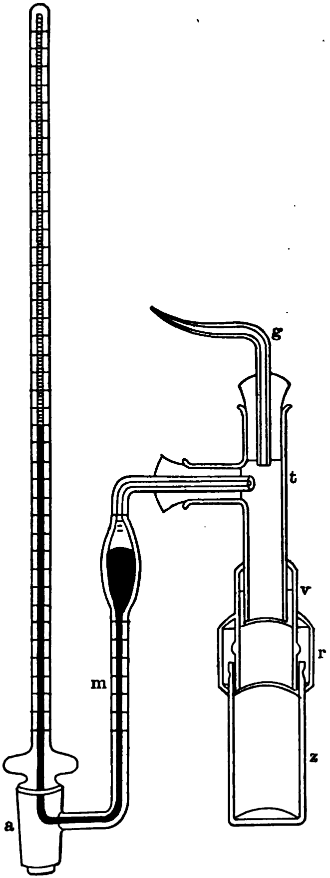

Fig. 14.

Practically, determinations of osmotic pressure are too difficult for common use. It has been demonstrated, however, that a mathematical relation exists between the lowering of the freezing point of a solvent and the osmotic pressure. (Van't Hoff, *Zeit. phys. Chem.* 1, 481; Ostwald, *Lehrbuch allgem. Chem.* 1, 760.)

If we let

C = the lowering of the freezing point of the solvent caused by a gram molecular weight* of a substance in 100 grams of the solvent,
L = the latent heat of fusion of a gram of the solvent, in calories,
T = the absolute temperature of the melting point of the solvent,

then it has been shown that

$$C = \frac{2T^2}{100L},$$

when no ionization or molecular aggregation of the substance dissolved takes place. The values for C are approximately correct only for solutions which are moderately dilute. Since the depression of the freezing point varies directly with the amount of the dissolved substance in a given quantity of the solvent, it follows from the definition of C as given above, that

$$C = \frac{M \times d}{S},$$

in which

M = the molecular weight of the dissolved substance.
S = the weight of the substance in 100 grams of the solvent.
d = the observed depression of the freezing point.

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* For example, 46 grams of alcohol, C_2H_6O, or 342 grams of cane sugar, $C_{12}H_{22}O_{11}$.

Since

$$S = \frac{100\,s}{S'},$$

if

s = weight of substance,
S' = weight of solvent,

we may write

$$C = \frac{M \times d \times S'}{100\,s},$$

or

$$M = \frac{C \times 100\,s}{d \times S'}.$$

These equations are in convenient form for practical use. The first may be used for the determination, empirically, of the value of *C* for a given solvent, by using some substance of known molecular weight. The second is used in determining unknown molecular weights. In an empirical form, this method of determining molecular weights was developed by Raoult before the relation to osmotic pressure was pointed out by van't Hoff.

The values of *C* for the solvents commonly used are:

Water	18.8°
Benzene	49.°
Phenol	75.°
Formic acid	27.7°
Acetic acid	38.8°
Nitro benzene	70.7°

The determinations are usually made with Beckmann's apparatus as shown in the figure. The side-neck tube is weighed to about 0.01 gram; about 15 cc. of the solvent are introduced, and the tube is weighed again. The thermometer is graduated to hundredths of a degree, and has a reservoir at the top containing mercury so that it can be set for use at any desired temperature. It should be so set that the freezing point of the solvent will come near the top of the scale. The thermometer and stirrer are then placed in the solvent, and the whole is placed in the glass tube, which serves as an air-jacket. This is surrounded with water or some liquid, which should be at a temperature of about 5° below the freezing point of the solvent. The solvent is slowly stirred, and the temperature allowed to fall slowly till the solvent begins to freeze. The temperature will always fall below the freezing point and will then rise as the ice separates. The thermometer should be tapped gently with a lead pencil as the temperature rises, and the highest point reached is taken as the freezing point. The temperature should not fall more than 0.2° to 0.3° below the freezing point of the solvent. The starting of the formation of ice may be aided by adding some pieces of platinum foil and, in extreme cases, by introducing a minute fragment of the frozen solvent.

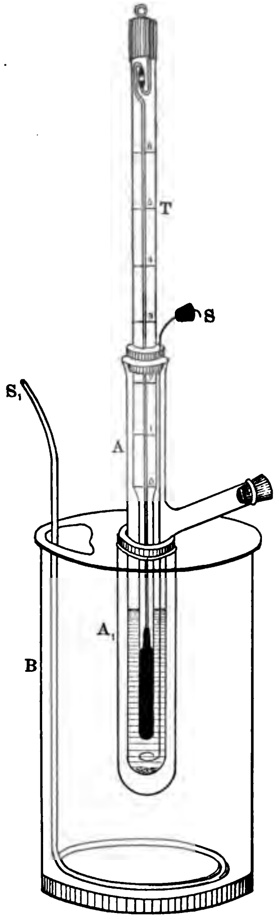

Fig. 15.

Correction for Overcooling. — A correction for overcooling may also be applied. The ice which separates consists of the pure solvent, and its separation causes an increase in the concentration in proportion to the amount of ice which separates. In the case of water, since the latent heat for the melting of ice is 80 calories, an overcooling of 1° will cause the separation of $\frac{1}{80}$ of the weight of the solvent in the form of ice. The concentration of the solution will be increased $\frac{1}{80}$ and the depression observed will be increased in the same proportion. Of course, overcooling of the pure solvent causes no change of concentration and introduces no error. On this basis, the corrections which must be subtracted from the observed depression for each degree of overcooling are as follows.

Water	1.25 per cent.
Benzene	0.96 " "
Formic acid	0.87 " "
Acetic acid	1.02 " "

To apply this correction, the lowest point reached by the thermometer must, of course, be observed. Each determination of the freezing point should be repeated two or three times, and successive observations should agree within two or three thousandths of a degree.

After the melting point of the pure solvent has been determined a weighed portion of the substance to be examined is added, and the determination repeated. An amount should be taken which will cause a depression of 0.3°–0.5°. This will be 0.12 to 0.20 gram for 15 grams of acetic acid and a substance having a molecular weight of 100. After determining the freezing point, a second and third portion of the substance may be added and the determinations repeated.

In using formic or acetic acid, especially, great care must be taken to avoid the admission of moisture, best by passing a current of dry air through the upper portion of the side-neck tube.

While the molecular weights, as determined by the freezing-point method, usually approximate closely to the true values, there are many cases in which the results do not agree with those determined by means of the vapor density. Thus alcohols and organic acids often give, in benzene, values for the molecular weight which are about twice too great, probably because of a molecular aggregation in these compounds. In water, on the other hand, strong acids and salts give values which are much too low, because of ionization.

Molecular aggregation appears to occur much less frequently in acetic acid than in some of the other solvents. It is, therefore, the most suitable solvent for general use.

Determination of Molecular Weights by Rise in the Boiling Point of Solutions.

The connection between the vapor pressure and osmotic pressure of a solution may be derived as follows: —

Suppose the cylinder, in the figure, to be filled with a solution and closed below by a semipermeable membrane. Suppose it to be immersed below in the pure solvent, and that the height of the column of liquid in the cylinder is such as to exactly balance the osmotic pressure. Suppose, also, that the whole is surrounded by an atmosphere consisting only of the vapor of the solvent. Under these circumstances, the vapor pressure of the pure solvent must be greater than the vapor pressure of the solution by exactly the pressure caused by the weight of a column of vapor of the same height as the column of liquid which balances the osmotic pressure; for if the difference in vapor pressure were less than this, the pure solvent would vaporize and the vapor would condense in the solution; or, if the difference in vapor pressure were greater than the pressure of the column of vapor, the vapor would condense below, and some of the solvent would vaporize from the solution above. Either result would cause a change in the height of the column of liquid, and this would be followed by the passage of the solvent through the semipermeable membrane; and the same process would be repeated indefinitely. In other words, we should have a perpetual motion set up in the system in spite of the friction in the membrane and on the walls of the cylinder. Such a conclusion is contrary to all experience, as expressed in the law of the conservation of energy. We must conclude, therefore, that the forces in the system are in equilibrium, and that the difference in vapor pressure between the solvent and solution is as stated.

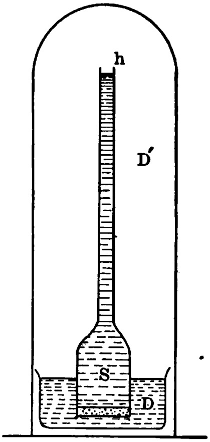

Fig. 16.

PROBLEM. — What is the height of the column of benzene vapor which corresponds to the difference in vapor pressure for the following data, assuming that the benzene vapor has the normal density corresponding to its molecular weight and the mean vapor pressure? What is the pressure exerted by a column of the solution of the same height, expressed in millimeters of mercury? What is the molecular weight of ethyl benzoate calculated from the osmotic pressure, volume of the solution, temperature of the experiment, and weight of ethyl benzoate present?

Weight of benzene (C_6H_6)	100.	grams.
" " ethyl benzoate ($C_6H_5CO_2C_2H_5$) . . .	2.47	"
Vapor pressure of pure benzene at 80°	751.86	mm.
" " " solution " "	742.60	"
Sp. gr. of solution at 80°	0.815	

Sp. gr. of mercury 13.59

1 cc. of the benzene vapor weighs

$$\frac{78.^*}{22390} \times \frac{747}{760} \times \frac{273}{353} \text{ gram.} = 0.00265 \text{ gram.}$$

(NERNST, *Theoretische Chemie*, p. 124.)

Practically, an accurate determination of vapor pressures has been found too difficult for common laboratory use. Since, however, for small changes in vapor pressure the differences in vapor pressure are directly proportional to the differences in boiling point, a determination of the rise in the boiling point of the solution will answer the same purpose as a determination of the lowering of the vapor pressure. The formula for calculating the results is the same used in case of the lowering of the freezing point, viz.:

$$M = \frac{100 \times C \times s}{r \times S'}.$$

M = Molecular weight.

C = Constant $= \dfrac{2\,T^2}{100\,L}$.†

s = Weight of substance.

S' = Weight of solvent.

r = Rise in boiling point.

The values for C are:

	C	BOILING POINT.
Ethyl ether	21.1	34.9°
Carbon bisulphide	23.7	46.°
Acetone	16.7	56.3°
Chloroform	36.6	61.2°
Ethyl alcohol	11.5	78.3°
Benzene	26.7	80.4°
Water	5.2	100.°

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[*] The molecular weight in grams divided by the normal volume in cubic centimeters.

[†] In this T is the absolute temperature of the boiling point, and L the latent heat of vaporization.

Acetic acid	25.3	118.°
Ethylene bromide	63.2	131.6°
Aniline	32.2	183.7°

Of the various forms of apparatus devised for making the determination, one of the simplest is that devised by H. C. Jones (Fig. 17). The vessel in which the boiling point is determined is about 18 cm. high and 4 cm. in diameter at the lower part. It is filled to a depth of 3 or 4 cm. with glass beads. The thermometer bulb is surrounded with a cylinder made by rolling up a piece of platinum foil to prevent radiation. Some pieces of platinum foil $\frac{3}{4}$ cm. square, with corners bent alternately up and down and edges serrated, are put inside of the cylinder to secure even boiling. The glass cylinder is closely wrapped with asbestos paper to a height of 12 cm., and the whole placed on a thick piece of asbestos cardboard having a hole $3\frac{1}{2}$ cm. in diameter in the center. On this opening is placed a piece of fine copper gauze, with which the glass is brought in contact. The connections for the thermometer and condenser must be with sound cork stoppers. The top of the condenser may be closed with a calcium chloride tube to advantage.

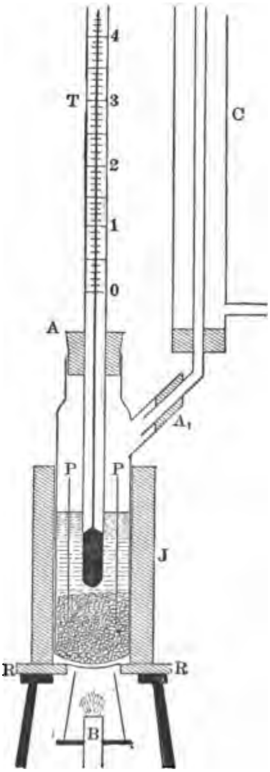

Fig. 17.

In making the determination the apparatus is weighed, the solvent is introduced and weighed, and the boiling point determined. The thermometer must be tapped occasionally with a lead pencil, and vigorous, regular boiling must be secured. The barometer should be read, and any change of pressure during the determination must be taken into account. A known weight of the substance is then introduced, either through the condenser, or, with high boiling solvents, through the side tube, and the determination of the boiling point is repeated. A correction, estimated at from 0.2 to 0.4 grams, according to the form of the apparatus and nature of the solvent, may be subtracted from the weight of the solvent because of the amount of the latter in the condenser and on the walls of the apparatus.

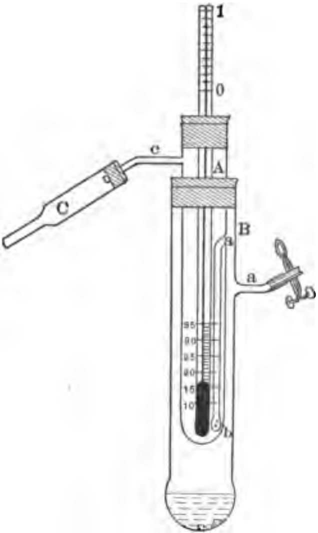

Fig. 18.

The low-boiling solvents, as ether and benzene, appear to be most satisfactory for general use.

Recently several forms of apparatus have been devised, in which the solution is boiled by the vapor of the solvent and overheating is avoided. One of the best of these is that of McCoy (*Am. Chem. J.* 23, 353) shown in Fig. 18. The volume of the solution is measured, instead of weighing it. The molecular weight is calculated by the formula, —

$$M = \frac{WT}{\Delta V}.$$

W = weight of substance in grams.
T = a constant.
Δ = the rise of the boiling point.
V = the volume of the solution in cubic centimeters.

The values of T for common solvents are:

Alcohol	1560	Carbon bisulphide	1940
Ether	3030	Acetone	2220
Chloroform	2600	Aniline	3820
Benzene	3280	Water	540

Determination of Molecular Weights by Means of Substitution Products. — If one or more atoms of a compound can be replaced by an atom or group of atoms, a comparison of the composition of the original substance with that of its substitution product will often decide as to the minimum possible molecular weight. Thus the simplest formula which agrees with the composition of acetic acid is CH_2O. The composition of sodium acetate (p. 21) cannot, however, be reconciled with any simpler formula than $Na\,C_2H_8O_2$.

As no salt of acetic acid can be found in which a larger proportion of hydrogen has been replaced, the formula of the acid must be $C_2H_4O_2$, or some multiple of that.

PROBLEM. — A hydrocarbon has the composition:

Carbon	92.31 per cent.
Hydrogen	7.69 per cent.

The simplest bromine substitution product of the hydrocarbon contains 50.96 per cent of bromine. What is the formula of the hydrocarbon?

For the determination of the molecular weights of acids the silver salts are often used, for bases the chlorplatinates (R_2PtCl_6) are usually suitable, and for hydrocarbons the halogen substitution products.

The following principles are also occasionally useful in deciding between possible formulas. Only one hydrocarbon containing an odd number of hydrogen atoms is now known. (Triphenylmethyl, Gomberg, *J. Am. Chem. Soc.* **22**, 757.) Also, only one compound is known in which the sum of the numbers of atoms of odd valence (H, Cl, Br, I, N, P, Na, etc.) is not an even number. These facts are, of course, connected with the fact that, as far as known, the valence of carbon is, with the single exception, always four or two.

Laboratory Exercises.

1. Determination of the melting point of urea, paranitrotoluene, succinic acid, salicylic acid, parahydroxybenzoic acid.
2. Fractional distillation of a mixture of alcohol and water; of 10 parts of benzene with 90 parts of alcohol and of 10 parts of alcohol with 90 parts of benzene, followed by a determination of the per cent of benzene in the first and last fractions of each case by precipitation with water; of a dilute hydrochloric acid and of a concentrated hydrochloric acid, with a determination of the specific gravity of the residual fraction; of the light oil from coal-tar.
3. Determination of carbon and hydrogen in cane sugar and in benzene.
4. Determination of carbon, hydrogen, and nitrogen in urea, uric acid, and paranitrotoluene; calculation of formulas.
5. Determination of bromine in bibrombenzene.
6. Determination of sulphur in sulphanilic acid.
7. Determination of silver in silver acetate.
8. Determination of water of crystallization and of calcium in calcium succinate.
9. Determination of the molecular weights of ether, chloroform, and benzene by Dumas' and by V. Meyer's methods.
10. Determination of the molecular weights of benzoic acid and of nitrobenzene in glacial acetic acid, by the freezing-point method.
11. Determination of the molecular weight of benzoic acid in benzene by the boiling-point method.

CHAPTER II.

PHYSICAL PROPERTIES.

In addition to melting point and boiling point, several other physical properties of organic compounds are of importance in their study, partly for purposes of identification, partly because relations have been discovered between some of these physical properties and the structure of some compounds. While these physical properties have, thus far, been very rarely useful in deciding questions of doubtful structure, it is altogether probable that some of them will prove increasingly valuable, for that purpose, in the future.

Specific Gravity. Molecular Volume. — Determinations of specific gravity with the hydrometer are only approximate unless spindles having a very small range and a slender stem are used. The Westphal balance (Fig. 19), if care is taken to have the liquid at the proper temperature, is rapid, and accurate to the third or fourth decimal place. The instrument should be carefully tested with pure water.

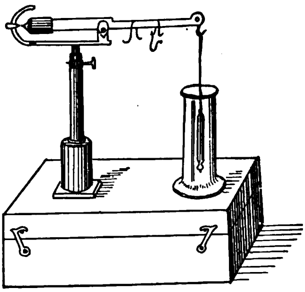

Fig. 19.

For greater accuracy, or for use with a small quantity of substance, some form of pycnometer is practically most useful. The form with a thermometer (Fig. 20) is very accurate when a sufficient quantity of material is available. A smaller form is useful for small quantities of material. The capacity may be from one to two cubic centimeters, and the neck, where the mark is placed, should be drawn down to an internal diameter of about one millimeter. The pycnometer may be easily filled, emptied, or dried by means of a pipette drawn out to a not too fine capillary. After filling, and allowing to stand in a bath of the proper temperature for ten minutes, the liquid above the mark may be removed by means of narrow slips of filter paper.


Fig. 20.

Specific gravities are referred either to water at the same temperature, or at 4°. Thus the symbol $D\frac{20^\circ}{4^\circ}$ is used to indicate the density of the substance at 20° as compared with water at 4°. If the specific gravity referred to water at 20° has been found, that referred to water at 4° may be calculated by subtracting 0.00174 for a substance having a specific gravity of one or a proportional amount for other specific gravities. The correction for other temperatures may be taken from tables giving the density of water.

Molecular Volume. — By molecular volume * is meant the volume in cubic centimeters occupied by a gram molecular weight of the substance, that is, by the number of grams corresponding to its molecular weight. It is found by dividing the molecular weight by the density. Thus the

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* The term *specific volume* was formerly used for this quantity.

density of ethyl alcohol, C_2H_6O, at its boiling point, is 0.73815. Its molecular volume is $\frac{46}{0.73815} = 62.32$.

A very large amount of work has been done for the purpose of collecting material on which to base an intelligent discussion of the relation between the composition of organic compounds and their molecular volumes. Kopp, who was the pioneer in this field (*Ann. d. Chem.* (Liebig), **41**, 79 (1842); **96**, 153, 303 (1855); **250**, 1, (1889), introduced the method of comparing molecular volumes at the boiling points of the compounds, and that method has been generally followed by others. In 1855 Kopp formulated the following general rules:

1. A difference of CH_2 causes a difference of 22 in the molecular volume.

The molecular volume of acetic acid, $C_2H_4O_2$ is 63.6
The molecular volume of propionic acid, $C_3H_6O_2$ is 85.5
Difference 21.9

2. One atom of carbon can be replaced by two atoms of hydrogen without changing the molecular volume.

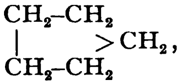
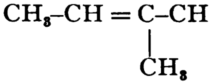
The molecular volume of ethyl benzoate, $C_6H_5CO_2C_2H_5$ is 173.6.

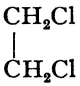
That of ethyl valerianate, $C_4H_9CO_2C_2H_5$ is 173.6.

That of amyl acetate, $CH_3CO_2C_5H_{11}$ is 174.4.

These rules were based on a considerable number of determinations from which the illustrations given have been selected. From these results Kopp drew the conclusion that the atomic volume of carbon is 11 and that of hydrogen 5.5 giving a total of 22 for the group CH_2. He also assigned the value of 12.2 as the atomic volume of carbonyl oxygen (in the group $C{=}O$) and 7.8 as that of hydroxyl oxygen. Values were also given for the atomic volumes of chlorine, bromine, iodine, nitrogen and sulphur. The values given later by Lossen for these elements are $Cl = 22.8$, $Br. = 29.1$, $I = 39.6$, $S = 23.5$, $N = 7$, $CN = 30$, $NO_2 = 32.6$.

A careful examination of the large amount of material which has now been accumulated, leads to the conclusion that molecular volumes calculated on the assumption of a constant atomic volume for each element are, in many cases, only approximate. Molecular volumes are, evidently, dependent, in part, on the structure of the compound, on the number of atoms in the molecule and on other factors, and it has not, hitherto, been possible to give to all of these factors a general, accurate, mathematical expression.

The following general statements are of interest. Some of them may possibly have a greater significance than is now understood. Double or triple unions (as in carbonyl, $C{=}O$, in unsaturated carbon compounds and probably in cyanogen, $C{\equiv}N$) increase the molecular volume. The formation of a ring, on the other hand, causes a decrease in the molecular volume. Thus the molecular volume of cyclopentane,  $\begin{array}{l}CH_2{-}CH_2\\ |\qquad\;\; {>}CH_2\\ CH_2{-}CH_2\end{array}$, is 93.2 at 20.5° while that of 2-methyl-2-butene,  $\begin{array}{l}CH_3{-}CH{=}C{-}CH_3\\ \qquad\qquad\quad |\\ \qquad\qquad\; CH_3\end{array}$, is 106.8, although the empirical formula of each is the same. The double union in one compound and the ring structure in the other are evidently connected with the large difference in molecular volumes.

Isomeric compounds, even when having similar structure, often have different molecular volumes. Thus the molecular volume of ethylene chloride,  $\begin{array}{l}CH_2Cl\\ |\\ CH_2Cl\end{array}$ at its boiling point, 84.1°, is 85.2, while that of ethylidene chloride at 57.7°, is 88.2.

In such cases the substance with the lower boiling point has, almost invariably, the greater molecular volume.

Surface Tension or Capillarity. — Comparatively few general relations have been found between the surface tension of organic liquids and their structure or composition. Determinations of the coefficient of surface tension have, however, given a means of determining the degree of molecular aggregation of liquids. (Ramsay and Shields, *J. Chem. Soc.* **63**, 1089 (1893).)

Practically, determinations of capillarity have proved useful for the determination of the strength of alcohol and of the amount of fusel oil in alcohol. For this purpose the determination is made either by determining the height to which the liquid will rise in a small tube or the number of drops given by a fixed volume of the liquid. An instrument used for the latter purposes is called a stalagmometer. (Traube, *Ber. d. chem. Ges.* **20**, 2644, 2824.)

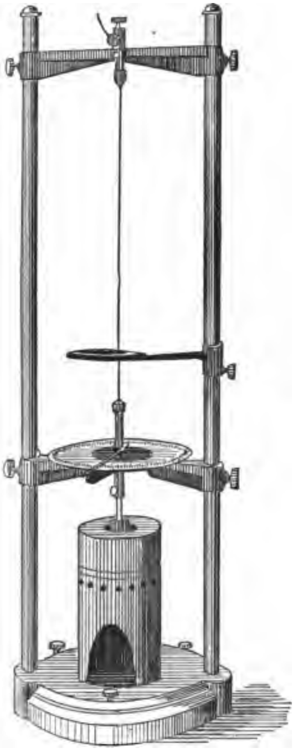


Fig. 21.

Viscosity. — Determinations of viscosity are usually made by determining the time required for a given volume of the liquid to pass through a capillary tube under a given difference of pressure. Such determinations are, thus far, of little theoretical interest, but are practically valuable in the study of machine oils. Another method of determination is founded on the resistance to a cylinder rotating in the oil. (Doolittle's Viscosimeter (Fig. 21), *J. Amer. Chem. Soc.* **15**, 173.)

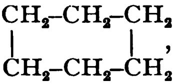
Critical Temperature. — This constant is most simply determined by heating the liquid in a sealed glass tube, in an air-bath, till the temperature is reached at which the boundary between liquid and vapor disappears. (Knietsch, *Ann. Chem.* (Liebig), 259, 116; Altschul, *Zeit. phys. Ch.* **11**, 581; **16**, 26.) Apart from its theoretical interest, the determination is of value in judging of the purity of a substance.

Specific Heat, Heat of Vaporization and Heat of Melting. — Determinations of these constants have proved, thus far, of little theoretical value in organic chemistry, except as connected with the lowering of the freezing point and the vapor pressure of solutions (pp. 26–37).

Heat of Combustion. — By heat of combustion is meant the heat, in calories, developed by burning one gram molecule of the substance to carbon dioxide and liquid water. It is most easily and accurately determined, for most substances, by burning in an autoclave in an atmosphere of compressed oxygen, the autoclave being surrounded with a known weight of water, the temperature of which is accurately taken before and after the combustion (Berthelot). The following are the most important general laws which have been established: —

In any homologous series the addition of a CH_2 group, *in an open chain*, increases the heat of combustion by about 158,000 gram-calories, or 158 Cal.

The heat of combustion of compounds containing only single unions between carbon atoms is less than that of compounds of the same composition containing double unions. Thus the heat of combustion of cyclohexane,



is less than that of hexene, $CH_3CH_2CH_2CH_2CH = CH_2$. This indicates that carbon atoms which are doubly united are not more firmly but, rather, less firmly held than those between which there is only a single union. Triple unions still further increase the heat of combustion.

Isomeric compounds of similar structure have very trifling differences, if any, in their heats of combustion.

Heat of Formation. — By heat of formation is meant the heat which would be developed on the combination of the elements to form one gram molecule of the substance. It is calculated by subtracting the heat of combustion of the substance from the heat of combustion of the elements of which it is composed.

By this method of calculation the heat of formation of some substances, as, for instance, that of acetylene, is negative. This can be satisfactorily explained only by assuming that carbon is combined with itself in amorphous carbon and that hydrogen is combined with itself in gaseous hydrogen.

Rationally, heat of formation would mean the heat resulting from the combination of the elements when in the free atomic state. In this sense, heat of formation cannot, at present, be experimentally determined, and all methods of calculation thus far proposed are dependent on uncertain hypotheses.*

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* For the sake of uniformity, the values for heats of combustion given in this book are taken, as far as possible, from the tables of Stohmann (*Zeit. für phys. Ch.* 6, 334 and 10, 410). In calculating heats of formation Stohmann assumes the heat of combustion of 12 grams of carbon as 94 Cal. and that of 2 grams of hydrogen as 69 Cal.

Molecular Refraction. — By molecular refraction is meant the constant calculated by the formula:

$$\frac{M(n^2-1)}{(n^2+2)d}.$$

M = Molecular weight.
n = Index of refraction (ratio of the sine of the angle of incidence to the sine of the angle of refraction, or ratio of the velocity of light in air to that in the substance).
d = Density or specific gravity.

The molecular refraction of compounds, for the red hydrogen line, may be calculated by means of the following "refraction equivalents" of the elements. (Brühl, *Zeit. phys. Ch.* 7, 191.)

C = 2.365
H = 1.103
O in OH = 1.506
O in C–O–C = 1.655
O in C = O = 2.328
N (as NC) = 2.76
Cl = 6.014
Br = 8.863
I = 13.808

Thus the molecular refraction of acetic acid calculated by means of these constants is:

For C_2 2.365 × 2 = 4.730
" H_4 1.103 × 4 = 4.412
" –O– = 1.506
" =O = 2.328
12.976

The actual determination gives the value 12.93.

The presence of a double union between carbon atoms increases the molecular refraction by 1.836, that of a triple union increases it by 2.22. This relation between refractive power and structure has sometimes proved useful in the study of compounds of unknown structure.

The index of refraction is determined by use of a hollow glass prism or by means of Pulfrich's refractometer. (See Ostwald, *Handbuch für physikalisch-chemische Messungen*, p. 170, or Walker's translation, p. 142.) The latter instrument, which depends on a determination of the angle of total reflection, is especially useful because only a very small quantity of the substance is required.

Molecular Dispersion. — This is calculated by the formula:

$$\frac{M(n_1^2 - 1)}{(n_1^2 + 2)\,d} - \frac{M(n^2 - 1)}{(n^2 + 2)\,d}.$$

M is the molecular weight and n and n_1 are the indices of refraction for two different lines of the spectrum. The dispersive as well as the refractive power is very considerably increased by the presence of double unions between carbon atoms.

Color. — A very large proportion of the carbon compounds are colorless, or, in powdered condition, white. Certain pretty well defined classes of compounds, and especially certain classes of nitrogen compounds, are brilliantly colored, however. Such compounds usually show, also, characteristic absorption spectra.

Rotation of the Plane of Polarized Light. — If a tube containing certain organic substances is placed in a ray of polarized light, the plane of polarization will be rotated through a definite angle, dependent on the nature of the substance, length of the tube, temperature, color of the light and nature of the solvent, if a solvent is used. The angle of rotation is determined by means of instruments called polarimeters or saccharimeters, according to their use and construction, the determination being frequently made for the commercial valuation of sugars. The *specific rotation*, $[\alpha]$, is calculated by the formula:

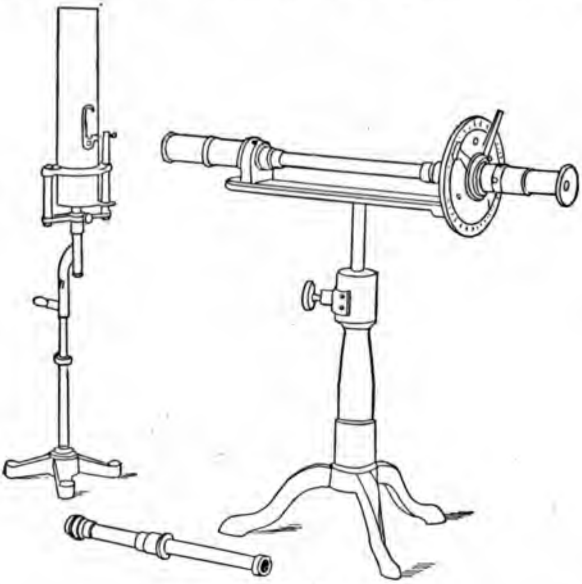

Fig. 22.

$$[\alpha] = \frac{100\,a}{l\,p\,d},$$

a = the observed angle of rotation,
l = the length of the column of liquid in decimeters,
p = the per cent of the substance present by weight,
d = the density of the solution.

It is sometimes convenient to substitute for *pd* the number of grams of the substance in 100 cc. of the solution. The specific rotation may be determined either for white light or for the sodium or some other light. If the sodium light is used, it is written $[\alpha]_D$. If white light is used, $[\alpha]_j$.

The relation between rotatory power and structure will be considered later.

Magnetic Molecular Rotation. — This has been defined by the formula,

$$\frac{rM}{r_1M_1d}.$$

r = the observed rotation in a given magnetic field,
M = the molecular weight of the substance,
d = the density of the substance,
r_1 = the rotation caused by water in the same field,
M_1 = the molecular weight of water = 18.

In some cases there appears to be a connection between the magnetic rotation and the constitution of carbon compounds. (W. H. Perkin, Sen., *J. Chem. Soc.*, 45, 421; 53, 561; 59, 981.)

Electrical Conductivity. — The measurement of the electrical conductivity of those organic compounds which dissociate in aqueous solutions, that is, of acids, bases, and salts, has given many results of value, and new applications of such determinations to the study of important problems are given every year.

The "specific resistance" of solutions * is usually taken as the resistance offered by a cube whose edge is 1 cm. The

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* The "specific resistance" is also sometimes defined as the resistance offered by a prism of 1 mm. cross section and 1 meter in length. As so defined it is 10,000 times greater than as defined in the text.

" specific conductivity " is the reciprocal of the " specific resistance." The " molecular conductivity," μ, is defined as the product of the volume of the solution, in cubic centimeters, which contains one gram molecule of the substance, multiplied by the specific conductivity of the solution.

Thus the specific conductivity of a $\frac{1}{50}$ normal solution of potassium chloride is 2.244×10^{-8} at 18°* or 2.594×10^{-8} at 25°. Since a $\frac{1}{50}$ normal solution contains one gram molecule in 50,000 cc., the molecular conductivity:

$$\text{At } 18° = 2.244 \times 10^{-8} \times 50{,}000 = 112.2,$$

$$\text{At } 25° = 2.594 \times 10^{-8} \times 50{,}000 = 129.7.$$

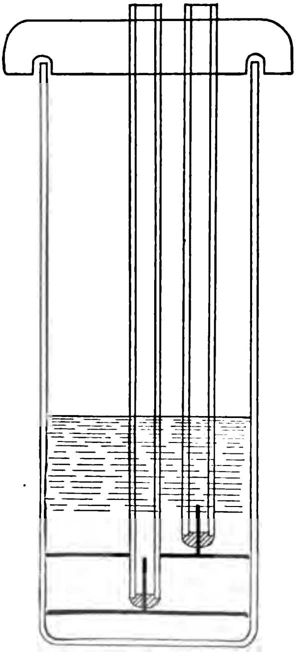

Fig. 23.

The determination of the absolute conductivity of a solution is attended with very considerable difficulty. Instead of this the determinations are usually made with a cell of the form shown in the figure. Two circular electrodes, 3 or 4 cm. in diameter, are attached with gold solder, or by welding, to stout platinum wires, which are then sealed into the ends of glass tubes which may be filled with mercury for convenient electrical connection. The con-

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* In Siemens's mercury units, which are usually employed in work of this kind. For conversion of conductivity into reciprocal ohms, see Kohlrausch and Holborn, *Leitvermögen der Elektrolyte*, 1898.

ductivity of some solution whose molecular conductivity is known (for example, that of a $\frac{1}{50}$ normal solution of potassium chloride) is first determined with the cell; the latter is then filled with the solution to be studied, and the measurement repeated, and, by comparison, the molecular conductivity of the solution can be easily calculated.

The measurements of resistance can be understood from the following diagram:

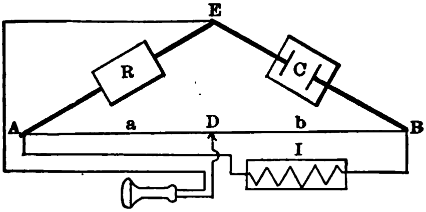


Fig. 24.

C is the cell whose conductivity is to be determined; *R* is a box of resistance coils; *AB* is a wire of uniform size, best of platinum or manganine (an alloy containing manganese); *D* is a sliding contact; *I* is an induction coil of high pitch, giving the necessary alternating current, as a direct current cannot be used because of polarization; *T* is a telephone. If the contact *D* is shifted till no sound is heard in the telephone, that is, till a current no longer passes between *D* and *E*, the resistance of the cell, r, will be to the resistance R, as $b : a$, or

$$r = R\frac{b}{a}, \quad \text{or} \quad C = \frac{a}{R \times b},$$

in which C is the conductivity of the solution in the cell, and a and b are the distances *AD* and *BD*. If we let c stand for the specific conductivity of the solution used, then the constant, k, of the cell may be defined as

$$k = \frac{c}{C} = \frac{c \times R \times b}{a}, \text{ or } c = k\frac{a}{R \times b}.$$

Having determined this constant, the specific conductivity of any other solution in the same cell will be

$$c' = k\frac{d'}{R' \times b'}.$$

And since the molecular conductivity is equal to the volume, v, occupied by one gram molecule multiplied by the specific conductivity (see above), the molecular conductivity is,

$$\mu = k\frac{v \times d'}{R' \times b}.$$

Preparatory to use the electrodes are covered with platinum black by electrolyzing a dilute solution of chlorplatinic acid in the cell. During the measurements the cell is kept at a constant temperature (usually 25°) in a thermostat. The water used for the solutions must be carefully purified, and especially must be free from carbonic acid and ammonia.

The conductivity of a solution of an electrolyte depends on two factors, — first on the velocities of the ions of which it is composed, and second, on the degree of dissociation of its molecules into ions.

At an infinite dilution the dissociation is complete, and at any other concentration the percentage dissociation, a, can be calculated by the formula,

$$a = \frac{\mu_v}{\mu_\infty}.$$

The value of μ_v is determined as indicated above. The value of μ_∞ for acids is determined by means of the molecular conductivity of their sodium salts. The velocity of the hydrogen ion is $u = 325$ at 25°, that of the sodium ion is $u = 49.2$. If therefore $325 - 49.2 = 275.8$ is added to the conductivity of the sodium salt at infinite dilution, μ_∞ for the acid is obtained. Since the sodium salts undergo a high degree of dissociation at moderate dilutions, and since the departure of the conductivity of the sodium salts from their maximum values is nearly the same for all acids, the following factors may be added instead of the one given above, when the molecular conductivity of the salt has been determined. v is the volume in liters occupied by one gram molecule of the salt.

$v =$	32	64	128	256	512	1024	∞
$k =$	287.8	285.8	283.8	281.8	279.8	277.8	275.8

For most complex acids the following empirical values may also be used:

For acids	containing		12	atoms	$\mu_\infty = 358$
"	"	"	15	"	$\mu_\infty = 356$
"	"	"	18	"	$\mu_\infty = 354$
"	"	"	22	"	$\mu_\infty = 352$
"	"	"	25	"	$\mu_\infty = 351$
"	"	"	30	"	$\mu_\infty = 350$

For bases $\mu_\infty + 1$ may be determined in a similar manner to the above, with the use of the nitrate.

In accordance with Ostwald's law of dilution,

$$\frac{a^2}{(1 - a)\,v} = \text{constant} = k.$$

In this formula a is the percentage dissociation, and v is the volume in liters occupied by one gram molecule of the acid, base, or salt. It is evident that for substances which are highly dissociated at a moderate dilution k will be large, and *vice versa.* k becomes, therefore, the most convenient measure of the degree of dissociation, or, as it is usually stated, of the *strength* of acids or bases. The value of this factor is a highly characteristic property of individual acids and bases, and will be often referred to in the following pages. For organic acids and bases a constant K ($=100\,k$), one hundred times greater than that given above, is usually employed. (Ostwald, *Zeit. phys. Ch.* 3, 174.)

Laboratory Exercises.

1. Determination of the specific gravity of kerosene with a hydrometer, with a Westphal balance, and with a pycnometer.
2. Determination of the viscosity of samples of machine oil.
3. Determination of the heat of combustion of naphthalene and of camphor in a bomb calorimeter; calculation of the heat of formation.
4. Determination of the molecular refraction of benzene.
5. Determination of $[\alpha]_D$ and $[\alpha]_j$ for cane sugar in an aqueous solution.
6. Determination of K for acetic acid, chloracetic acid and benzoic acid.
7. Determination of the basicity of succinic and benzoic acids (Ostwald, *Handbuch für physiko-chemische Messungen*, p. 281, or Walker's translation, p. 235).

CHAPTER III.

HYDROCARBONS. MARSH-GAS SERIES.

In an important sense the hydrocarbons, or compounds of carbon and hydrogen, are looked upon as the fundamental compounds of organic chemistry from which all other compounds are derived. This is partly because very few carbon compounds, comparatively speaking, are known which do not contain hydrogen; partly because it is practically convenient to consider carbon compounds as substitution products of the hydrocarbons, that is, as substances in which other elements or groups of elements have taken the place of hydrogen atoms in the hydrocarbons.

As regards their empirical formulae, all of the hydrocarbons may be classified in groups or "series," in each of which the number of hydrogen atoms bears a fixed mathematical relation to the number of carbon atoms.

In the first or limiting series (Ger., *Grenzkohlenwasserstoffe*) the general formula is C_nH_{2n+2}, the successive members having the formulae, CH_4, C_2H_6, C_3H_8, etc. This is known as the marsh-gas series from its first member.

Members of the second series have the general formula, C_nH_{2n}; of the third series, C_nH_{2n-2}. Members of each successive series up to that having the general formula, C_nH_{2n-40}, are known. One hydrocarbon of the series, C_nH_{2n-54}, is also known.

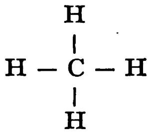
MARSH-GAS SERIES, OR PARAFFINS, C_nH_{2n+2}.

		Boiling Point.	Melting Point.	Specific Gravity.	
CH_4	Methane	−152°	−186°	0.415 at −164°	
C_2H_6	Ethane	− 90°	——	——	
C_3H_8	Propane	− 37°	——	——	
C_4H_{10}	Butane	+ 1°	——	0.60	(0°)
	Methylpropane	− 11.5°	——	——	
C_5H_{12}	Pentane	36°	——	0.6337	(15°)
	Methylbutane	31°	——	0.6271	(15°)
	Dimethylpropane	9°	−20°	——	
C_6H_{14}	Hexane	69°	——	0.6654	(15°)
	2 Methylpentane	62°	——	0.6766	(0°)
	3 Methylpentane	64°	——	0.6765	(20.5°)
	2, 3 Dimethylbutane	58°	——	0.6680	(17.5°)
	2, 2 Dimethylbutane	49.6°	——	0.6488	(20°)
C_7H_{16}	Heptane	98.4°	——	0.6885	(15°)
	2 Methylhexane	90.3°	——	0.7067	(0°)
	3 Methylhexane	91°	——	0.6895	(20°)
	3 Ethylpentane	95°–98°	——	0.689	(27°)
	3, 3 Dimethylpentane	86°–87°	——	0.7111	(0°)
C_8H_{18}	Octane	125.5°	——	0.7188	(0°)
	2, 5 Dimethylhexane	108.5°	——	0.6975	(15°)
C_9H_{20}	Nonane	149.5°	−51°	0.7217	(15°)
	2, 6 Dimethylheptane	132°	——	0.7247	(0°)
$C_{10}H_{22}$	Decane	173°	−30°	0.7342	(15°)
	2 Methylnonane	150°–160°	——	——	
	2, 7 Dimethyloctane	160°	——	0.7358	(9.8°)
	3, 6 Dimethyloctane	159°–162°	——	0.7463	(22°)

The normal hydrocarbons (p. 66) of the series are known, and are named, logically, from the Greek numerals, up to tetracosane, $C_{24}H_{50}$. A few of still higher molecular weight are known, the highest having the formula $C_{60}H_{122}$.

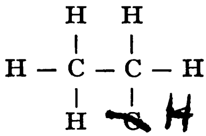
Homology. — A consideration of the general formula for the series shows that it is dependent on the valence of carbon and that of hydrogen. In a molecule containing two carbon atoms one valence, or power of combination,* of each carbon atom must be used to hold the molecule together, and but three valences of each atom will be available for combination with hydrogen atoms. With three carbon atoms two valences of one carbon atom must be used in holding to the other two, and one valence of each of the other atoms must be employed in a similar manner, leaving but eight of the twelve valences of the three carbon atoms available for combination with hydrogen. The bearing of these statements as applied to the successive members of the series will be more apparent from the following graphical formulae:

Methane



$$\begin{array}{ccccc} & & H & & \\ & & | & & \\ H & - & C & - & H \\ & & | & & \\ & & H & & \end{array}$$

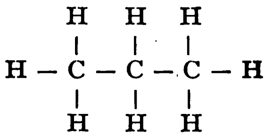
Ethane



$$\begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ H & - & C & - & C & - & H \\ & & | & & | & & \\ & & H & & \cancel{C} & H & \end{array}$$

C_2H_6

Propane



$$\begin{array}{ccccccccc} & & H & & H & & H & & \\ & & | & & | & & | & & \\ H & - & C & - & C & - & C & - & H \\ & & | & & | & & | & & \\ & & H & & H & & H & & \end{array}$$

It is apparent that the successive members differ from each other by the group CH_2, and that the addition of one carbon atom renders possible the addition of two hydrogen atoms. This relation is characteristic of all other series of hydrocarbons as well as of the paraffins, and is known as

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* Sometimes called bonds or linkages. The terms valence, or power of combination, are, perhaps, less definite, and correspond better to our very imperfect knowledge of the forces within the molecule.

homology. The series are called *homologous series*, and any hydrocarbon or compound is said to be a *homologue* of hydrocarbons or compounds in the same series containing a different number of carbon atoms.

Methane or Marsh-gas, CH_4.— This is the only hydrocarbon known containing but one atom of carbon in the molecule. It is formed in nature by the decomposition of vegetable matter covered with water, and comes to the surface in an impure form when the decaying organic matter on the bottom of a shallow pool of water is stirred with a pole. This gave rise to the name *marsh-gas*. The gas appears to be formed by the action of micro-organisms, and it has been demonstrated in the laboratory that filter paper (cellulose, $(C_6H_{10}O_5)_n$, will decompose in the presence of water, under the influence of the micro-organisms found in sewage with the formation of methane.

The methane given off from the seams of coal, and known as *fire-damp*, has, very probably, a similar origin. Methane has also been found existing under high pressure in the pores of rocks covered with an impervious layer of shale or similar material. When a hole is bored into such a rock the gas escapes; and it has proved of great economic value in Pennsylvania, Ohio, Indiana and elsewhere under the name of *natural gas*. The gas usually contains some nitrogen and larger or smaller quantities of ethane, or other homologues, and of hydrogen sulphide. It has never been found to contain hydrogen. Natural gas has also been long known in the Caucasus, giving rise there to the sacred fires of the Parsees.

The origin of natural gas is still uncertain. The most probable theory about it would seem to be that it has been formed by the decomposition of vegetable or animal matter in a manner similar to that by which the gas of the marshes is produced.

Another theory (Mendelejeff's) is that it is formed by the action of water on metallic carbides. This theory has received some support recently by the discovery that aluminum carbide is decomposed by water with the formation of methane (Moissan).

$$Al_4C_3 + 12\,H_2O = 3\,CH_4 + 4\,Al\,(OH)_3.$$

Methane is formed when almost any form of organic matter is heated to a high temperature, and so forms a considerable proportion of coal gas and of oil gas. It is also formed in small amounts when hydrogen is brought in contact with heated carbon, and, hence, is found in very small amount in water-gas.

Marsh-gas may be obtained by passing a mixture of carbon bisulphide and hydrogen sulphide over heated copper.

$$CS_2 + 2\,H_2S + 8\,Cu = CH_4 + 4\,Cu_2S.$$

These methods of preparation are not practically useful, but they are interesting because, theoretically, they may be made the starting point for the preparation of nearly all of the other hydrocarbons and other compounds of the series, and indeed, of other series as well. They form a part of the evidence which has demonstrated that there is no real difference between "organic" and "inorganic" compounds.

Methane is most easily prepared by heating a mixture of dry, fused sodium acetate with four times its weight of soda-lime, in a tube or retort of hard glass.

$$CH_3\,\boxed{CO_2Na + NaO}\,H = CH_4 + Na_2CO_3.$$

Pure methane may also be prepared by dropping a mixture of alcohol, methyl iodide, and a drop of sulphuric acid, on a copper-zinc couple. The couple can be prepared by heating gently a mixture of copper powder with three parts of powdered zinc and allowing it to cool in a closed flask.

$$CH_3I + H_2 = CH_4 + HI \quad \text{or}$$
$$2\,CH_3I + 2\,Zn + 2\,H_2O = 2\,CH_4 + ZnI_2 + Zn\,(OH)_2.$$

These methods are, both of them, general, and may be used for the preparation of a great number of hydrocarbons, of this and of other series.

Methane is a colorless, tasteless gas. It is the lightest compound gas known. What is its density?

It may be condensed to a liquid by high pressure, but only at low temperatures, its critical temperature being — 76°. Under atmospheric pressure it boils at about — 152°. It solidifies at — 186°.

In its chemical properties methane is very stable. Its kindling temperature (670°) is higher than that of hydrogen (650°) or of amorphous carbon (375–500°). This is one reason for the efficiency of the Davy safety lamp, and is a cause of some difficulty in the use of natural gas in gas engines, and in the explosion of mixtures of methane and air in gas analysis.

Mixtures of chlorine and methane explode violently in direct sunlight. In diffused daylight, the action is more gentle, and substitution products are formed.

$$CH_4 + Cl_2 = \underset{\text{Methyl chloride.}}{CH_3\,Cl} + H\,Cl.$$

If the substitution is carried to its limit, carbon tetrachloride, CCl_4, is formed, but the reaction has not been practically useful because of the difficulty of confining it to the formation of a single product.

Ethane. — C_2H_6. This may be prepared:

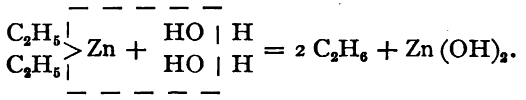
1. By treatment of ethyl iodide, C_2H_5I, mixed with alcohol and a drop of sulphuric acid with the zinc-copper couple, or by warming ethyl iodide with water and zinc dust.

2. By the electrolysis of acetic acid, CH_3CO_2H, or its salts. The anion CH_3CO_2 which is liberated at the positive pole decomposes at once into carbon dioxide and methyl, CH_3, and the latter combines with itself to form ethane, $CH_3\text{–}CH_3$. This method of preparation is of especial interest because it demonstrates the presence of two methyl groups in ethane, and furnishes a confirmation of the graphical formula which has been based on theoretical reasons (p. 57). The presence of a methyl group in acetic acid and in sodium acetate is demonstrated by the preparation of methane from the latter.

$$C_2H_3O_2Na + NaOH = CH_4 + Na_2CO_3.$$

It is evident from this reaction that in sodium acetate the three hydrogen atoms were all combined with the same carbon atom.

3. By dropping water cautiously into cooled zinc ethyl.



$$\begin{matrix} C_2H_5 \\ C_2H_5 \end{matrix}\!\!> Zn + \begin{matrix} HO \mid H \\ HO \mid H \end{matrix} = 2\,C_2H_6 + Zn\,(OH)_2.$$

From the methods of preparation it is evident that we may look upon ethane as composed of two methyl groups, or as composed of an ethyl (C_2H_5) group and hydrogen. It is important to notice that the different methods of preparation give the same compound, and that the ethyl group must contain one methyl group. (Schorlemmer, *Ann. d. Chem.* (Liebig), 131, 76; 132, 234.)

The names *methyl*, *ethyl*, *propyl*, *butyl*, etc., are given to the groups formed by the removal of one hydrogen atom from the corresponding hydrocarbons.

Ethane is a gas, but may be condensed to a liquid more easily than methane. The liquid boils at −90°. In chemical properties ethane resembles methane quite closely. It burns with a somewhat more luminous flame, but the illuminating power is only one-half that of ethylene.

Propane. — This may be prepared from propyl iodide, C_3H_7I, or from zinc propyl, $Zn(C_3H_7)_2$, by methods similar to those given for ethane.

Propane condenses to a liquid at −17°. It is very slowly absorbed by fuming sulphuric acid, and appears to be slightly more reactive than methane or ethane, but is very indifferent toward most chemical agents.

Substitution Products of Propane. — When one hydrogen atom of propane is replaced by a halogen atom, or by some group of atoms, two classes of compounds may be obtained. An understanding of the relation between these two classes of compounds is necessary before the butanes can be intelligently discussed.

When ethyl iodide, CH_3CH_2I, is heated with potassium cyanide, ethyl cyanide, CH_3CH_2CN, is formed.

$$C_2H_5I + KCN = C_2H_5CN + KI.$$

When ethyl cyanide is properly treated with sulphuric acid, it is decomposed with the formation of propionic acid, $CH_3CH_2CO_2H$, and ammonium sulphate.

$$\begin{aligned} &2\,CH_3CH_2CN + H_2SO_4 + 4\,H_2O \\ &\quad = 2\,CH_3CH_2CO_2H + (NH_4)_2SO_4. \end{aligned}$$

In the fusel oil which is obtained as a by-product in the manufacture of common alcohol there is found a small amount of normal propyl alcohol which has the empirical formula C_3H_8O. If this alcohol is oxidized by means of a mixture of potassium pyrochromate and dilute sulphuric acid, the same propionic acid which is obtained from ethyl cyanide is formed.

$$C_3H_8O + 2\,O = CH_3CH_2CO_2H + H_2O.$$

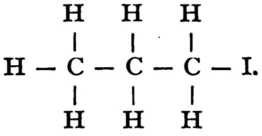
On the other hand, if normal propyl alcohol is treated with red phosphorus and iodine, it is converted into normal propyl iodide, C_3H_7I.

$$5\,C_3H_8O + 5\,I + P = 5\,C_3H_7I + H_3PO_4 + H_2O.$$

The relations which have been sketched will be clearer from the following diagram:

$$\begin{tikzcd}
CH_3CH_2I \arrow[r, "KCN"] & CH_3CH_2CN \arrow[r, "H_2SO_4"] & CH_3CH_2CO_2H \\
& C_3H_7I & C_3H_8O. \arrow[l, "P+I"'] \arrow[u, "K_2Cr_2O_7 + H_2SO_4."']
\end{tikzcd}$$

These relations demonstrate that normal propyl iodide contains the ethyl group, CH_3CH_2-, and that the iodine is combined with the end carbon atom. The only graphical formula consistent with these relations and with the valence of the atoms concerned is the following:



$$\begin{array}{ccccccccc}
 & & H & & H & & H & & \\
 & & | & & | & & | & & \\
H & - & C & - & C & - & C & - & I. \\
 & & | & & | & & | & & \\
 & & H & & H & & H & &
\end{array}$$

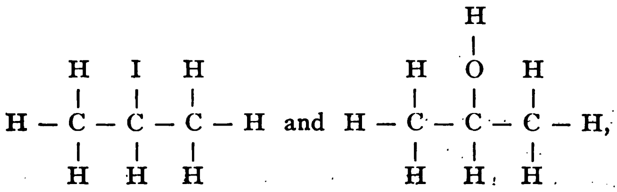
When calcium acetate is heated it decomposes, and acetone distils over.

$$\mathrm{Ca}{<}\begin{matrix}C_2H_3O_2\\C_2H_3O_2\end{matrix} = CaCO_3 + \underset{\text{Acetone.}}{C_3H_6O.}$$

If acetone is reduced by means of sodium amalgam, isopropyl alcohol, C_3H_8O, is formed. This gives, with iodine and red phosphorus, isopropyl iodide, C_3H_7I. When either isopropyl alcohol or acetone is oxidized a mixture of acetic and formic acids is obtained.

$$\underset{}{C_3H_8O} + 4O = \underset{\text{Acetic acid.}}{C_2H_4O_2} + \underset{\text{Formic acid.}}{CH_2O_2} + H_2O.$$

This difference in the conduct of isopropyl alcohol as compared with normal propyl alcohol can be satisfactorily explained only by supposing that the oxygen in the former is combined with the central instead of the end carbon atom. Since the iodine of isopropyl iodide takes the place of this oxygen and one hydrogen atom, it follows that the iodine in that compound must be combined with the central carbon atom. This gives the graphical formulae:



$$\begin{array}{ccccccc} & H & & I & & H & \\ & | & & | & & | & \\ H - & C & - & C & - & C & - H \\ & | & & | & & | & \\ & H & & H & & H & \end{array} \quad \text{and} \quad \begin{array}{ccccccc} & & & H & & & \\ & & & | & & & \\ & H & & O & & H & \\ & | & & | & & | & \\ H - & C & - & C & - & C & - H, \\ & | & & | & & | & \\ & H & & H & & H & \end{array}$$

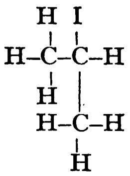
for isopropyl iodide and isopropyl alcohol.

Isomerism. — Different compounds having the same percentage composition are often met with among the carbon compounds. Such compounds are said to be *isomers*. If isomers have the same molecular weight, as in the case just considered, they are called *metamers*. If they have different molecular weights, as, for instance, acetylene, C_2H_2, and benzene, C_6H_6, they are called *polymers*.

Isomers differ, of course, in their physical or chemical properties, and usually in both. Thus normal propyl iodide boils at 102.2°, isopropyl iodide at 89.5°. Normal propyl iodide has a specific gravity of 1.7557 at 15°, isopropyl iodide a specific gravity of 1.7109. When isopropyl iodide is heated with water at 100° in a sealed tube, isopropyl alcohol and hydriodic acid are formed. Undoubtedly normal propyl iodide would, under the same conditions, give normal propyl alcohol, but the experiment has not, apparently, been tried.

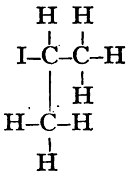
Graphical Formulae. — Formulae similar to those which have been given for the two propyl iodides are frequently very useful as giving a concise expression to the knowledge gained about the structure of carbon compounds. It should be remembered that such formulae are of value and trustworthy only when they are based on a careful study of the methods of formation and of decomposition of the compounds for which they are given.

As ordinarily used, such formulae express merely the view which is held as to what atoms within the molecule are in direct combination with each other, and are not intended, further than that, to represent stereomeric or space relations within the molecule. For this reason, formulae may often be written which appear, at first sight, very different but which represent identical structures. Thus the formulae



$$\begin{array}{ccccccc} & & H & & I & & \\ & & | & & | & & \\ H & - & C & - & C & - & H \\ & & | & & | & & \\ & & H & & | & & \\ & & H & - & C & - & H \\ & & & & | & & \\ & & & & H & & \end{array}$$

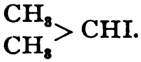
and



$$\begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ I & - & C & - & C & - & H \\ & & | & & | & & \\ & & | & & H & & \\ H & - & C & - & H & & \\ & & | & & & & \\ & & H & & & & \end{array}$$

have the same structural significance as that already given for isopropyl iodide because each formula represents the same atoms as in direct combination with each other.

Arrangement in Space. — It has been found, it is true, that a considerable number of compounds cannot be satisfactorily understood without a more definite discussion of the arrangement of their atoms in space; and this has given good reason for the belief that certain definite space relations must exist between the atoms in all compounds. This more definite view is reserved for a later discussion.

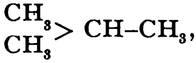
In most cases it is convenient to use somewhat abbreviated graphical formulae. Thus isopropyl iodide is usually written, $CH_3{-}CHI{-}CH_3$, or  $\begin{matrix}CH_3\\CH_3\end{matrix}{>}CHI$. To save space, such formulae are often used where fuller formulae would, perhaps, be better. Until the beginner has become thoroughly familiar with their exact meaning, he will find it useful, occasionally, to expand such formulae into their full graphical form.

Butanes, C_4H_{10}. — Since butane must be considered as a propane in which one hydrogen atom has been replaced by a methyl group, the discussion of the propyl iodides leads us to expect two isomeric butanes. This expectation is verified by experience.

Normal* butane, $CH_3{-}CH_2{-}CH_2{-}CH_3$, is prepared by heating ethyl iodide with zinc, or by treating it with sodium amalgam.

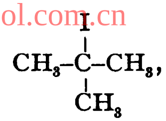
$$2\ CH_3CH_2I + 2\ Na = CH_3CH_2CH_2CH_3 + 2\ NaI.$$

The structure of the compound is evident from the method of formation. Normal butane is a gas which condenses to a liquid that boils at 1°.

Isobutane, or 2-methyl propane,  $\begin{matrix}CH_3\\CH_3\end{matrix}{>}CH{-}CH_3$, is pre-

* By "normal" is meant a hydrocarbon in which no carbon atom is combined directly with more than two others.

pared by dropping tertiary butyl iodide (2-methyl-2-iodo-propane [*]),



$$\begin{array}{c} I \\ | \\ CH_3-C-CH_3, \\ | \\ CH_3 \end{array}$$

on zinc covered with water, or by boiling isobutyl iodide (2-methyl-1-iodo-propane) $\begin{matrix} CH_3 \\ CH_3 \end{matrix} > CH-CH_2I$ with zinc dust and water.

$$2\ C_4H_9I + 2\ Zn + 2\ H_2O = 2\ C_4H_{10} + ZnI_2 + Zn\,(OH)_2.$$

Isobutane boils at — 11.°5.[†] The chemical properties of the butanes are similar to those of propane. They are indifferent toward most chemical agents except chlorine and bromine. Each of them gives two mono-substitution products. What would be the graphical formulae of the chlorbutanes?

Pentanes, C_5H_{12}. — If a methyl group is substituted for one hydrogen in each of the butanes, two pentanes will be obtained from each, according as the substitution takes place in connection with a central or an end carbon atom. An examination of the resulting formulae shows, however, that two of the pentanes obtained are structurally identical. This agrees with the results of experience, as but three pentanes have been prepared. A simpler discussion of the theoretically possible formulae for the pentanes is based on a consideration of each hydrocarbon as a derivative of the hydrocarbon corresponding to the longest chain of carbon atoms in its molecule. It is evident that we can have but one pentane with a chain of five carbon atoms. This is *normal pentane*.

1 $CH_3CH_2CH_2CH_2CH_3$.

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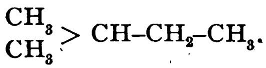
[*] For nomenclature, see p. 68. [†] Determined by E. F. Phillips under my direction.

With a chain of four carbon atoms, the attachment of a methyl group to either of the end carbon atoms would give a chain of five atoms; i.e., normal pentane. An attachment of the group to either central carbon atom, since these are symmetrically placed in the molecule, would give the same *methyl-butane*, or, as it was formerly called, *isopentane*.

2.

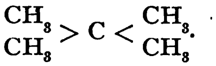


$$\begin{matrix}CH_3\\CH_3\end{matrix}> CH{-}CH_2{-}CH_3.$$

No other arrangement of five carbon atoms, giving a chain of four, is possible.

With a chain of three carbon atoms, the only manner by which two carbon atoms can be attached without giving a chain of four atoms is by attaching two methyl groups to the central carbon atom. This gives *dimethyl propane*, or *tetramethyl methane*.

3.



$$\begin{matrix}CH_3\\CH_3\end{matrix}> C <\begin{matrix}CH_3.\\CH_3\end{matrix}$$

The three pentanes have been prepared by methods which leave no doubt as to their structure; but a discussion of the methods used is not necessary here.

It is noticeable that throughout the series the isomer with a longer carbon chain has a higher boiling point. The differences in specific gravity are slight, and the difficulty of securing absolute purity is so great that no law in the matter can be considered as established.

Hexanes, C_6H_{14}; Official Nomenclature. — Five hexanes are possible. The theoretical formulae for these may be easily derived by using the principle of the longest carbon chain as applied above in the case of the pentanes. The same principle is applied in the *official nomenclature* * for the hydro-

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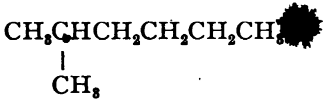
* Adopted by a congress of chemists held at Geneva in 1892. *Am. Chem. J.* 15, 50, *Ber. d. chem. Ges.* 26, 1595 (1893).

carbons of the series and their derivatives. In this system of nomenclature each compound is to be considered as a derivative of the hydrocarbon corresponding to the longest chain of carbon atoms in the compound. To indicate the points of attachment for the various side chains, or substituting atoms, or groups, the carbon atoms are numbered, beginning at the end nearest to a side chain.

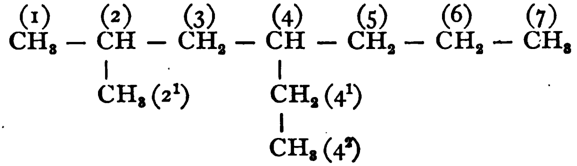
Thus



$$CH_3\underset{\substack{|\\ CH_3}}{C}HCH_2CH_2CH_2CH_3$$

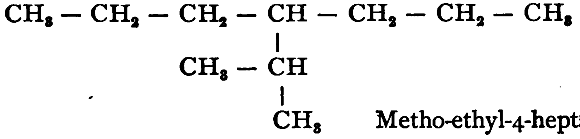
is methyl-2-hexane. $CH_2ICH_2CH_3$ is iodo-1-propane.

In the case of side chains containing two or more carbon atoms, the latter receive a second smaller number beginning with the one nearest the point of attachment, thus:—



$$\begin{array}{ccccccccccccc}
(1) && (2) && (3) && (4) && (5) && (6) && (7)\\
CH_3 & - & CH & - & CH_2 & - & CH & - & CH_2 & - & CH_2 & - & CH_3\\
&& | &&&& | &&&&&&\\
&& CH_3\,(2^1) &&&& CH_2\,(4^1) &&&&&&\\
&&&&&& | &&&&&&\\
&&&&&& CH_3\,(4^2) &&&&&&
\end{array}$$

When a hydrocarbon radical is introduced in a side chain it is designated by the prefixes metho-, etho-, etc., instead of the usual methyl, ethyl, etc. Thus:—



$$\begin{array}{ccccccccccccc}
CH_3 & - & CH_2 & - & CH_2 & - & CH & - & CH_2 & - & CH_2 & - & CH_3\\
&&&&&& | &&&&&&\\
&&&& CH_3 & - & CH &&&&&&\\
&&&&&& | &&&&&&\\
&&&&&& CH_3 &&&&&&
\end{array}$$

Metho-ethyl-4-heptane.

In a strict application of the official nomenclature the names pentane, hexane, etc., are reserved for the *normal* hydrocarbons; i.e., for those having no side chains, or, in other words, for those in which no carbon atom is directly united to more than two others.

HIGHER MEMBERS OF THE METHANE SERIES.

The number of possible isomers increases very rapidly for hydrocarbons having a greater number of carbon atoms. The theory indicates the possibility of nine heptanes, C_7H_{16}, 75 decanes, $C_{10}H_{22}$, and 802 tridecanes, $C_{13}H_{28}$. At present, however, only five heptanes are known, and only a comparatively very small number of isomers containing a larger number of carbon atoms. The student will find it useful to develop the possible formulae for the hexanes and heptanes as a means of securing a better understanding of the possibilities of structural isomerism. A further discussion of the subject here is unnecessary.

Many of the normal hydrocarbons of the series have been prepared by methods which establish their structure.

Normal octane has been prepared from normal butyl iodide and sodium.

$$2CH_3CH_2CH_2CH_2I + 2Na = CH_3(CH_2)_6CH_3 + 2NaI.$$

Normal decane, $CH_3(CH_2)_8CH_3$, has been prepared in a similar manner from normal octyl bromide, ethyl iodide and sodium, and *normal eikosane* from normal decyl iodide, $CH_3(CH_2)_8CH_2I$, and sodium.

GENERAL PROPERTIES OF THE PARAFFINS.

The first four members of the series are gases at ordinary temperatures. Normal pentane boils at 36°, normal hexane at 69°, and the boiling point increases with the number of carbon atoms but the differences grow less. From tetradecane, $C_{14}H_{30}$, upward, the hydrocarbons are white, solid, wax-like bodies at temperatures above 0°. The specific gravity also increases more and more slowly, and is nearly constant at 0.78 for the higher members.

Chemically, the paraffins are very inert, chlorine in direct sunlight being about the only agent which readily attacks them.[*] It has been found recently, however, that nitro-derivatives and sulphonic acids may be obtained by the action of dilute nitric acid, and of concentrated sulphuric acid on some of them. (Konowalow, *Ber. d. chem. Ges.* **28**, 1852; **29**, 2199, Worstall, *Am. Chem. J.* **20**, 202 and 664.)

Petroleum. — In certain limited areas in Pennsylvania, Ohio, Indiana, Texas, California, and Canada, on the shores of the Caspian Sea, and in a few other places in Europe, large natural reservoirs filled with a crude oil known as petroleum are found. These reservoirs are covered with an impervious layer of shale or other rocks which have prevented the escape of the oil. When a hole is bored through this impervious layer the petroleum is usually forced to the surface by the hydrostatic pressure of the water found below, and often flows in enormous quantities. After a time the flow decreases, and may then, usually, be increased by exploding a charge of nitroglycerine in the bottom of the well to break up and open seams in the rocks below. The composition of the petroleum from different sources varies considerably. American oils consist largely, though by no means exclusively, of hydrocarbons of the marsh-gas series. The oils from the Caspian Sea contain considerable quantities of cyclic hydrocarbons of the general formula C_nH_{2n}. California petroleum contains considerable amounts of benzene and its homologues. In all cases, petroleum is a very complex mixture. Compounds of the marsh-gas series have been ob-

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[*] The name paraffin (meaning "with little affinity") is given because of this inert character.

tained from it by prolonged fractional distillation, and by treatment with concentrated sulphuric acid and with nitric acid to remove members belonging to other series. The hydrocarbons which have been isolated in this manner have been identified by their boiling points, specific gravities, vapor densities, and especially by means of their chlorine derivatives and the compounds which can be prepared from these by simple reactions. (Schorlemmer, *Proc. Roy. Soc.*, Vols. 14, 15, 16, 18, 19, and 20; Warren, *Am. J. Sci.*, Vols. 39, 40, 41, 44, and 45; *Proc. Am. Acad. Arts and Sci.*, 9, 177 (1867), Mabery, *Ann. chem. J.* **19**, 243, 374, 419, 482, 796.)

Caucasus petroleum. (Beilstein and Kurbatow, *Ber. d. chem. Ges.* **13**, 1818; **14**, 1620; Markownikow, *Ibid.* **16**, 1873; **20**, 1850; *Ann. d. chem.* (Liebig), **234**, 89. Origin of petroleum, Engler, *Ber. d. chem. Ges.* **21**, 1816; **22**, 592; **26**, 1449; **33**, 7; Kraemer and Spilker, *Ibid.* **32**, 2940; **35**, 1212.)

Most of the hydrocarbons which have been isolated from the American petroleum have been normal, but recently 2, 3-dimethyl butane has been found in Russian petroleum (Aschan), and the presence of methyl-propane in American petroleum seems probable (Mabery). The Ohio, Indiana, and Canadian petroleums contain sulphur compounds consisting in part of methyl sulphide $(CH_3)_2S$, ethyl sulphide $(C_2H_5)_2S$ and other sulphides of the aliphatic series. (Mabery and A. W. Smith, *Am. Chem. J.* **13**, 233.)

For commercial purposes petroleum is purified by subjecting it at first to a crude fractional distillation, which is usually carried on till only a residue of coke remains in the retort. The high temperatures during the last part of the distillation cause the decomposition or "cracking" of the higher boiling portions, and so increase the portion of medium boiling point, which is most valuable. The oils are further purified by agitation with concentrated sulphuric acid, with a solution of sodium hydroxide, and with water. Oils containing sulphur are purified by boiling them with fine copper oxide. The copper sulphide formed is regenerated by roasting it in furnaces. Finally, the portion to be used as kerosene is distilled with steam to remove the lower boiling portions and raise the "flashing-point" (see below) as high as required.

The commercial products, in order of boiling point, are:

Cymogene and *rhigolene*, used sometimes in artificial-ice machines. *Ligroin* or *petroleum ether*, an especially purified low-boiling product much used as a solvent in laboratories. *Low-boiling gasoline* which is sufficiently volatile so that air saturated with its vapor may be burned as an illuminating gas. *High-boiling gasoline* used in gasoline cook-stoves. *Naphtha* and *benzine* used for cleansing purposes, and usually nearly or quite identical with high-boiling gasoline. *Kerosene* of various grades, used in lamps. *Paraffin oils* and other high-boiling oils used for lubricants. *Vaseline*, a high-boiling, semisolid body used for medical purposes. *Paraffin* obtained by cooling the high-boiling portions to a low temperature, and separating the solid portion by means of a large filter press; used for the manufacture of candles and in electrical insulation. All of these substances are, of course, complex mixtures from which definite compounds can be isolated only with great difficulty.

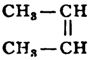
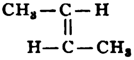
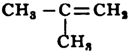
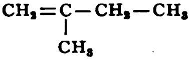
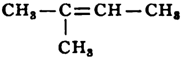
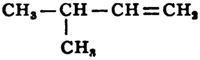
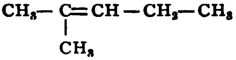
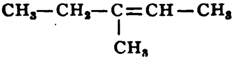
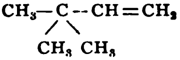
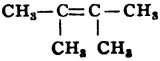
Flashing-point.— The safety of *kerosene* depends largely on the absence from it of hydrocarbons which might escape in sufficient amount to form an explosive mixture with air. The presence of such hydrocarbons is determined by the *flashing-test.* In its simplest form the determination consists in placing some of the oil in a small beaker with a thermometer and warming slowly till a small flame, which is brought near the surface of the oil at regular intervals, causes a momentary flash. More reliable forms of apparatus have been proposed, but have not been adopted for general use. A minimum flashing-point of 65.5° (150° F) has been fixed by most of our States.

Laboratory Exercises.

1. Preparation of methane.
2. Preparation of ethane. Determination of its density.
3. Comparison of the conduct of benzine and of benzene toward concentrated sulphuric acid, and toward a mixture of sulphuric and nitric acids.
4. Determination of the flashing-point of a sample of petroleum.

CHAPTER IV.

ETHYLENE SERIES. UNSATURATED HYDROCARBONS.

NAME.	FORMULA.	BOILING POINT.	SPECIFIC GRAVITY.
Ethene	$CH_2=CH_2$	− 103°	—
Propene	$CH_3-CH=CH_2$	− 48.5°	—
1-Butene	$CH_2=CH-CH_2CH_3$	− 5°	
Cis-2-butene	 $\begin{matrix}CH_3-CH\\ \Vert\\ CH_3-CH\end{matrix}$	+ 1.5°	0.635 (13.5°)
Trans-2-butene	 $\begin{matrix}CH_3-C-H\\ \Vert\\ H-C-CH_3\end{matrix}$	+ 2.5°	
Methyl-propene	 $CH_3-\underset{\displaystyle CH_3}{\underset{\vert}{C}}=CH_2$	− 6°	
1-Pentene	$CH_2=CH-CH_2-CH_2-CH_3$	40°	—
2-Pentene	$CH_3-CH=CH-CH_2-CH_3$	36°	—
2-Methyl-1-butene	 $CH_2=\underset{\displaystyle CH_3}{\underset{\vert}{C}}-CH_2-CH_3$	32°	0.670
2-Methyl-2-butene	 $CH_3-\underset{\displaystyle CH_3}{\underset{\vert}{C}}=CH-CH_3$	36.8°	0.6783 (0°)
2-Methyl-3-butene	 $CH_3-\underset{\displaystyle CH_3}{\underset{\vert}{CH}}-CH=CH_2$	21.2°	—
1-Hexene	$CH_2=CH-CH_2-CH_2-CH_2-CH_3$	68°-70°	—
2-Hexene	$CH_3-CH=CH-CH_2-CH_2\ CH_3$	67°	0.6997 (0°)
2-Methyl-2-pentene	 $CH_3-\underset{\displaystyle CH_3}{\underset{\vert}{C}}=CH-CH_2-CH_3$	66°	0.702 (0°)
3-Methyl-3-pentene	 $CH_3-CH_2-\underset{\displaystyle CH_3}{\underset{\vert}{C}}=CH-CH_3$	70°	0.712 (0°)
2.2-Di-methyl-3-butene	 $CH_3-\underset{\displaystyle CH_3\ CH_3}{\underset{/\ \backslash}{C}}-CH=CH_2$	70°	—
2.3-Di-methyl-2-butene	 $CH_3-\underset{\displaystyle CH_3}{\underset{\vert}{C}}=\underset{\displaystyle CH_3}{\underset{\vert}{C}}-CH_3$	73°	0.712 (0°)

Six heptenes, six octenes, and two nonenes of known structure have been prepared. A considerable number have also been obtained for which the structure is uncertain.

Empirically, members of the second series of hydrocarbons have the general formula, C_nH_{2n}. In reality there are two series having this formula, the ethylene or ethene series and the saturated, cyclic series.

Ethylene or Ethene, C_2H_4.— The first member of the series should be *methylene*, CH_2, but all attempts to obtain such a compound have proved unsuccessful. A number of compounds, such as carbon monoxide, $C = O$, hydrocyanic acid, $H - N = C$, and others may be considered as derivatives of methylene, and the properties of some of these indicate that methylene, if momentarily formed, would prove so reactive as to combine at once with itself to form ethylene or some other polymer.

Ethylene, C_2H_4, is usually prepared by mixing ethyl alcohol, C_2H_5OH, with one and two-thirds times its volume of concentrated sulphuric acid and heating the mixture to about 175°. The alcohol at first reacts with the sulphuric acid to form ethyl sulphuric acid, and this decomposes at the temperature given with the formation of ethylene and sulphuric acid,

$$C_2H_5OH + H_2SO_4 = \underset{\text{Ethyl sulphuric acid.}}{C_2H_5HSO_4} + H_2O$$

$$C_2H_5HSO_4 = C_2H_4 + H_2SO_4.$$

At a lower temperature ether, $(C_2H_5)_2O$, (p. 165), is formed, and the ethylene is always contaminated with that and other impurities.

Pure ethylene may be obtained by warming an alcoholic solution of ethylene bromide, $C_2H_4Br_2$, with granulated zinc.

$$C_2H_4Br_2 + Zn = C_2H_4 + ZnBr_2.$$

Both methods are general and may be applied to the preparation of many other hydrocarbons of the series and to the preparation also of their derivatives from alcohols and hydroxyl compounds, and from bromine compounds having two bromine atoms combined with adjacent carbon atoms.

Ethylene is formed when almost any carbon compound is subjected to destructive distillation. It is present in coal gas and oil gas, and is very important in giving illuminating power.

Ethylene is a colorless gas with a sweetish odor. Its kindling temperature is 580°, very considerably below that of methane and ethane. In this as in many other properties, ethylene is less stable than members of the marsh-gas series.

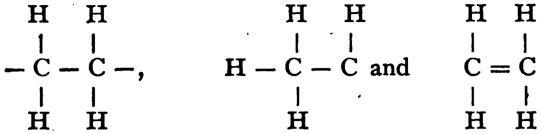
Ethylene combines directly with chlorine or bromine to form ethylene chloride, $C_2H_4Cl_2$, or ethylene bromide, $C_2H_4Br_2$. These are colorless oils of a pleasant odor, and the formation of the former gave to ethylene its old name of *olefiant gas*. At 100° ethylene unites directly with hydrobromic or hydriodic acid to form ethyl bromide, C_2H_5Br, or ethyl iodide, C_2H_5I. A cold, neutral solution of potassium permanganate oxidizes it to ethylene glycol.

$$C_2H_4 + O + H_2O = \underset{\text{Ethylene glycol.}}{C_2H_4(OH)_2}.$$

Unsaturated Compounds. — These reactions are all of them characteristic not only of ethylene but of its homologues, and of almost all of their derivatives, whether belonging to this or to other series. From this point of view, their importance can scarcely be overestimated. The conduct of these compounds toward the halogens and the halogen acids has given rise to the term *unsaturated*, as applied to them. The radical difference between their conduct and the conduct of saturated compounds of the marsh-gas series should be noticed.

If heated to a high temperature with hydrogen, ethylene combines with it to form ethane; if heated alone, methane, ethane, free carbon, acetylene, C_2H_2, benzene, C_6H_6, naphthalene, $C_{10}H_8$ and many other compounds are formed.

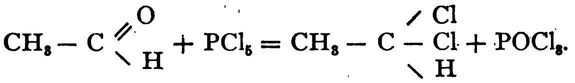
Structure of Ethylene. — Theoretically, three formulae seem to be possible for ethylene in accordance with the valence of carbon and of hydrogen. These are:



$$\begin{array}{cc} H & H \\ | & | \\ -C- & C-, \\ | & | \\ H & H \end{array} \qquad \begin{array}{ccc} & H & H \\ & | & | \\ H- & C- & C \\ & | & \\ & H & \end{array} \text{ and } \begin{array}{ccc} H & & H \\ | & & | \\ C & = & C \\ | & & | \\ H & & H \end{array}$$

The first formula, at first thought, appears to have much in its favor because of the satisfactory explanation it gives of the "unsaturated" nature of ethylene. It represents the carbon atoms as practically trivalent, however, and, if carbon can in reality act as a trivalent element, we can see no reason why such groups as CH_3, C_2H_5, etc., should not be capable of an independent existence. All reactions which should lead to the formation of these and similar groups give instead ethane, $CH_3 - CH_3$, butane, $C_2H_5 - C_2H_5$, or other compounds in which the two groups are united, and carbon shows its normal valence. In the whole list of hydrocarbons not a single one with an odd number of hydrogen atoms is known, unless we suppose triphenylmethyl, $(C_6H_5)_3C$, to exist momentarily as a dissociation product of hexaphenylethane (p. 115). But the triphenylmethyl formed in this way is so extremely reactive that the existence of a similar condition in ethylene seems very improbable.

If the second formula represents the structure of ethylene, the compound, ethylene chloride, formed by the addition of chlorine would be 1.1. di-chlorethane, CH_3CHCl_2, while, if the third formula is correct, it must be 1.2. di-chlorethane, $CH_2Cl - CH_2Cl$. Now 1.1. dichlorethane, or as it is more often called, ethylidene chloride, has been prepared by treating acetaldehyde with phosphorus pentachloride.



$$CH_3-C\begin{matrix}/\!\!/O\\ \diagdown H\end{matrix}+PCl_5=CH_3-C\begin{matrix}/Cl\\ -Cl\\ \diagdown H\end{matrix}+POCl_3.$$

The structure of acetaldehyde is deduced from the fact that it gives acetic acid, CH_3–CO_2H by oxidation, and that acetic acid, in turn, must contain a methyl group from the manner in which it gives methane (p. 59) and ethane (p. 61) by its decomposition. The structure of acetic acid has also been thoroughly established by its synthesis.

$$CH_3HSO_4\xrightarrow{KCN}CH_3CN\xrightarrow{HCl}CH_3CO_2H.$$

Ethylidene chloride (1,1-dichlorethane) boils at 57.5° and has a specific gravity of 1.2044 at 0°, while ethylene chloride boils at 83.5° and has a specific gravity of 1.2803. Since only two dichlorethanes are theoretically possible, and the structure of ethylidene chloride is established, ethylene chloride, which is different, must be 1,2-dichlorethane, CH_2ClCH_2Cl. Such a formula for ethylene chloride leads to either the first or third formula for ethylene. As the first has already been excluded, the formula $CH_2{=}CH_2$ remains as the most probable expression for its structure.

Double Unions. — The term "double union" gives, at first thought, the impression that carbon atoms which are "doubly united" must be held together more firmly than those which are singly united. Such a conclusion is completely contradicted by the facts in the case. The point of double union is always one of weakness, and is usually the point where the compound is most easily attacked by oxidizing agents or otherwise. On account of this, some authors have objected to the use of the term "double union." No very satisfactory equivalent for it has, however, been proposed.

Homologues of Ethylene. — The homologues of the series may be prepared by methods similar to those given for ethylene. They may also be formed by warming halogen derivatives of the marsh-gas series with an alcoholic solution of caustic potash.

$$\underset{\text{Butyl iodide.}}{CH_3CH_2CH_2CH_2I} + KOH = \underset{\text{1-Butene.}}{CH_3CH_2CH = CH_2} + KI + H_2O.$$

Nomenclature. — In the official nomenclature the names correspond to the names of the methane series, the vowel *a* being replaced by *e*. A number is used to indicate the position of the double union, when necessary. The presence of the double union greatly increases the number of possible isomers. There are three butenes and five pentenes. Illustrations of the use of the system of nomenclature will be found in the table at the beginning of this chapter.

Physical Properties. — Members of the ethene series have a slightly higher boiling point than the corresponding members of the methane series. The specific gravity is also somewhat higher. The heat of combustion is less than that of the corresponding member of the methane series, but the difference is not so great as the loss of two hydrogen atoms would lead us to expect.

The heats of combustion are:

Ethane	389 Cal.	Dif. 53 Cal. (?)
Ethene	336 Cal.	
Propane	541 Cal.	Dif. 41 Cal.
Propene	500 Cal.	
Dimethyl propane	847.1 Cal.	Dif. 39.5 Cal.
Methyl-2-butene	807.6 Cal.	

The combustion of two grams of hydrogen gives 68.4 Cal., hence the union of hydrogen with members of the ethylene series must be accompanied by the evolution of a considerable amount of heat.

The differences in the heats of formation (see p. 45) for the two series are even more significant. These are:

Ethane	6	Cal. (?)
Propane	17	Cal.
Dimethyl propane	37	Cal.
Ethene	—10	Cal.
Propene	—11	Cal.
Methyl-2-butene	— 7.4	Cal.

The determinations on which these calculations are based were made by different observers, and are not all concordant, but it appears to be established beyond question that the heat of formation of the members of the marsh-gas series is always positive while that of the members of the ethylene series is negative. This accords with the greater stability of the former.

Laboratory Exercises.

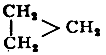
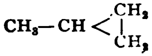
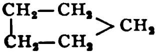
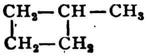
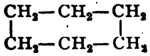
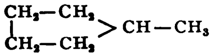
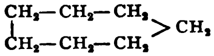
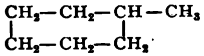
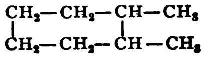
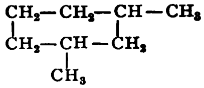
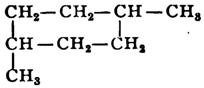
1 Preparations of ethylene and of ethylene bromide.

2. Compare the conduct of benzine, benzene and turpentine when shaken with a dilute solution of potassium permanganate. Turpentine is an "unsaturated" hydrocarbon, though it does not belong to this series.

3. Preparation of isoamylene (2 methyl-3-butene).

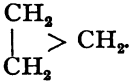
CHAPTER V.

CYCLIC HYDROCARBONS, C_nH_{2n}.

		BOILING POINT.	SPECIFIC GRAVITY.
Cyclopropane		−35°	—
Methyl cyclopropane		+5°	0.6912 (20°)
Cyclopentane		50°—51°	0.7506 (20°)
Methyl cyclobutane		39°—42°	—
Cyclohexane		81°	0.7783 (20°)
Methyl cyclopentane		72°	0.7508 (20°)
Cycloheptane		118°	0.809 (20°)
Methyl cyclohexane		101°	0.7694 (20°)
1.2 Di-methyl cyclohexane		116°—118°	0.7733 (20°)
1.3 Di-methyl cyclohexane		120°	0.769 (19°)
1 4 Di-methyl cyclohexane		119°—120°	0.769 (18°)

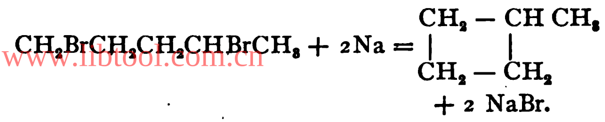
A considerable number of other cyclic hydrocarbons of this series are known.

In the second series of hydrocarbons having the general formula C_nH_{2n} instead of the double union between adjacent carbon atoms which is characteristic of the ethylene series, the carbon atoms are united to form a ring-like structure. Since these compounds and their derivatives, especially when the ring contains four or more carbon atoms, resemble compounds of the methane series rather than those of the ethylene series, they are given the same names as the former, but with the prefix *cyclo*. The application of this nomenclature will be apparent from the table.

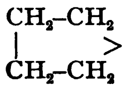
Cyclopropane,  $\begin{matrix}CH_2\\ | \\ CH_2\end{matrix} > CH_2$. This is prepared by warming 1.3 dibrompropane (trimethylene bromide), $CH_2Br-CH_2-CH_2Br$, with alcohol of 75 per cent and zinc-dust. Cyclopropane is a gas which liquefies under a pressure of five or six atmospheres. It combines directly with bromine to form 1.3 dibrompropane, but the reaction takes place less easily than that of propene, $CH_3CH=CH_2$, with bromine. This reaction, as well as its method of formation, demonstrates its structure. It combines with hydriodic acid to form 1–iodo-propane. Propene, on the contrary, gives 2–iodo-propane, CH_3CHICH_3.

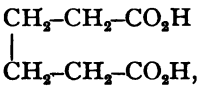
Cyclopropane does not reduce a cold, neutral solution of potassium permanganate. Members of the ethene series and their derivatives reduce such a solution instantly. As the test is easily applied, it serves as a very useful, practical means of diagnosis for distinguishing the two classes of compounds. (Baeyer, *Ann. Chem.* (Liebig), **245**, 146.)

Cyclobutane has not been prepared, but the possibility of its preparation is rendered almost certain by the preparation of *methylcyclobutane* from 1, 4-dibrompentane and sodium.



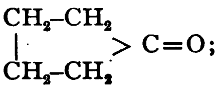
Methyl cyclobutane does not combine directly with hydriodic acid, and all of the properties of the derivatives of cyclobutane indicate that a ring containing four carbon atoms is more stable than one containing three.

Cyclopentane,  $> CH_2$, has been prepared by the following series of reactions: Adipic acid,

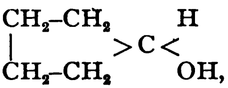


$$\begin{array}{l} CH_2\text{–}CH_2\text{–}CO_2H \\ | \\ CH_2\text{–}CH_2\text{–}CO_2H, \end{array}$$

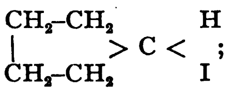
when distilled with lime gives cyclopentanon,



this gives, on reduction, cyclopentanol,

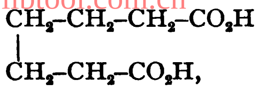


and this, when treated with hydriodic acid, yields iodocyclopentane,



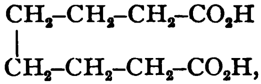
this, by another reduction, gives cyclopentane.

Cyclohexane and Cycloheptane have been prepared from pimelic acid,



$$\begin{array}{l} CH_2-CH_2-CH_2-CO_2H \\ | \\ CH_2-CH_2-CO_2H, \end{array}$$

and suberic acid,



$$\begin{array}{l} CH_2-CH_2-CH_2-CO_2H \\ | \\ CH_2-CH_2-CH_2-CO_2H, \end{array}$$

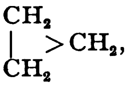
by means of similar reactions.

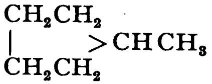
Attempts to prepare *cycloöctane* have been, thus far, unsuccessful. It seems, therefore, that the series reaches a natural limit with the ring containing seven carbon atoms, and that rings containing a larger number of atoms will be prepared only with great difficulty, if at all.

This fact, and also that of the stability of the five, six, and seven carbon atom rings, appear to be of fundamental importance. They have given a strong support to a theory with regard to the structure of carbon compounds which was originally based on relations which were found to exist between the optical activity of carbon compounds and their structure (see p. 137).

Heat of Combustion. — The addition of a CH_2 group causes an increase of 158 Cal. to the heat of combustion of most hydrocarbons, and this might lead us to expect that the heats of combustion of the hydrocarbons of this series would be simply multiples of that quantity.

For cyclohexane (C_6H_{12}), 933.2 Cal. (155.5 × 6), and methylcyclohexane (C_7H_{14}), 1095. Cal. (156.4 × 7), the values approximate those which we should expect on the supposition that the hydrocarbons consist of CH_2 groups united together. It is interesting to notice that the heat of combustion is, however, somewhat less, and so the heat of formation is *greater* than the calculated values. What is true of the molecular volumes of cyclic compounds (p. 42)? Is there any probable connection between the two sets of facts?

For trimethylene,  $\left.\begin{matrix}CH_2\\|\\CH_2\end{matrix}\right>CH_2$, on the other hand, the heat of combustion (499.4 = 3 × 166.5) is considerably greater, and the heat of formation is less than those calculated, indicating a condition of instability in the compound. It is of interest to notice, too, that the heat of combustion of propene, $CH_3CH = CH_2$ (p. 80), is practically identical with that of trimethylene or cyclopropane.

Occurrence of Cyclic Hydrocarbons. — Cyclopentane, cyclohexane and their derivatives have been found in considerable amounts in Russian petroleum from the region of the Caucasus. Cyclohexane and many of its derivatives have been prepared by the reduction of derivatives of benzene. When benzene itself is reduced by means of hydriodic acid at a high temperature (280°) it is converted, in part at least, into methylcyclopentane,  $\left.\begin{matrix}CH_2CH_2\\|\\CH_2CH_2\end{matrix}\right>CH\,CH_3$ (Zelinsky, *Ber. d. Chem. Ges.* **28**, 1023; **30**, 388). This fact is of especial interest from its bearing on the theory of the structure of cyclic compounds according to which a saturated ring containing five carbon atoms should be more stable than one containing six atoms (p. 193).

Laboratory Exercises.

The saturated cyclic hydrocarbons are not very easily prepared. Cyclopropane and cyclohexane would be as well adapted as any for illustrative work.

CHAPTER VI.

SERIES C_nH_{2n-2}, C_nH_{2n-4}, and C_nH_{2n-6}.

ACETYLENE SERIES, C_nH_{2n-2}.

		BOILING POINT.	SPECIFIC GRAVITY.
Acetylene	$CH \equiv CH$	—84°	0.451 (0°)
Allylene	$CH_3-C \equiv CH$	—	—
Propadiene	$CH_2=C=CH_2$	—	—
3-Butine	$CH \equiv C-CH_2-CH_3$	14°	—
2-Butine	$CH_3-C \equiv C-CH_3$	17°—18°	—
1,3-Butadiëne	$CH_2=CH-CH=CH_2$	—	—

SERIES C_nH_{2n-4}.

Valylene	$CH_3-CH=CH-C \equiv CH$(?)	50°	

SERIES C_nH_{2n-6}.

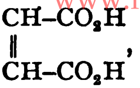
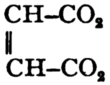
Di-propargyl, (1,5-Hexadiine)	$CH \equiv C-CH_2-CH_2-C \equiv CH$	86°—87°	0.819 (0°)
2,4-Hexadiine	$CH_3-C \equiv C-C \equiv C-CH_3$	129°—130° (?)	—

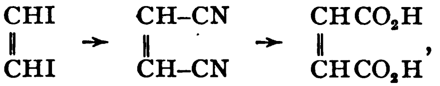
Acetylene, $CH \equiv CH$, and acetylidene $CH_2=C$ (?) — Acetylene is formed in small amounts when carbon and hydrogen are brought together at the temperature of the electric arc (3000° — 3500°).

When calcium carbonate is heated with carbon, in an electric arc, calcium carbide, CaC_2, is formed. This gives, on treatment with water, acetylene and calcium hydroxide.

$$CaCO_3 + 4\,C = CaC_2 + 3\,CO$$
$$CaC_2 + 2\,H_2O = Ca(OH)_2 + C_2H_2.$$

This method of preparation is commercially important as a means of making acetylene for illuminating purposes.

Acetylene is also formed by the electrolysis of fumaric or maleïc acid. Both of these acids have the structure,  $\begin{array}{l}CH-CO_2H\\ \| \\ CH-CO_2H\end{array}$, (p. 257) and are separated by electrolysis into hydrogen and the complex ion,  $\begin{array}{l}CH-CO_2\\ \| \\ CH-CO_2\end{array}$. The latter then decomposes into acetylene $CH \equiv CH$ and carbon dioxide, the decomposition being somewhat analogous to that of acetic acid (p. 61). This method of preparation, together with the synthesis of fumaric acid from acetylene iodide through the following series of compounds,



$$\begin{array}{l}CHI\\ \| \\ CHI\end{array} \rightarrow \begin{array}{l}CH-CN\\ \| \\ CH-CN\end{array} \rightarrow \begin{array}{l}CH\,CO_2H\\ \| \\ CH\,CO_2H\end{array},$$

furnish satisfactory evidence that the hydrogen atoms in acetylene are combined with different carbon atoms.

Acetylene is formed in small amounts when a Bunsen burner "snaps back" so that the gas burns in contact with a moderately cool surface and with a limited supply of air. If the products of combustion are passed through an ammoniacal solution of cuprous chloride a precipitate of copper carbide, Cu_2C_2 (often called copper acetylide), is formed. From this, acetylene may be regenerated by treatment with dilute hydrochloric acid, or with a solution of potassium cyanide.

Acetylene may be prepared by treating ethylene bromide with alcoholic potash or, better, with a solution of sodium ethylate in absolute alcohol.

$$CH_2Br-CH_2Br + 2NaOC_2H_5 = \\ CH \equiv CH + 2\,NaBr + 2\,C_2H_5OH.$$

This method of preparation is similar to the preparation of butene from butyl iodide (p. 80).

Acetylene is a gas which liquefies at 1° under a pressure of forty-eight atmospheres. It is usually described as having a pungent, disagreeable odor, and the unpleasant odor emitted by a Bunsen burner when burning at the base has been ascribed to the acetylene which is one of the products of such combustion. It seems to have been established, however, that pure acetylene has a garlic-like but not a penetrating odor. Professor Nef has suggested that the gas obtained by some processes may be a mixture of true acetylene, $CH \equiv CH$, with acetylidene, $CH_2 = C$. He considers that the latter would have a penetrating, disagreeable odor and be extremely poisonous. Pure acetylidene has not been obtained, but a number of compounds supposed to be substitution products of the body have been prepared. The evidence as to their structure is not, however, altogether satisfactory.

Acetylene combines directly with chlorine or bromine to form 1,1,2,2, tetrachlor-, or tetrabrom-ethane, $CHBr_2CHBr_2$, respectively. If silver acetylide, Ag_2C_2, is treated with bromine, however, tetrabrom-ethylene, C_2Br_4, is formed.

Structure of Acetylene. — The structural formula of acetylene is usually written $CH \equiv CH$. A part of the evidence that the hydrogen atoms are united with different carbon atoms has been given. The significance of the triple union represented between the two carbon atoms is not clear. That it does not mean that the carbon atoms are held together more firmly than they would be held by a single union is evident from the chemical properties of acetylene and its homologues. That three of the four powers of combination possessed by each carbon atom are used in holding the two carbon atoms together seems probable, but such a form of union is evidently unstable.

The instability of the molecule is especially evident from the heat of combustion of acetylene which is 310.1 Cal. This gives for acetylene a *negative* heat of formation of − 47.8 Cal. This means that 26 grams of acetylene would evolve 47.8 Cal. if decomposed into hydrogen gas and carbon. This fact, which, a few years ago, possessed only a theoretical interest, has become of great practical importance, since it indicates that acetylene may decompose explosively under some conditions. The gas cannot be stored safely under a pressure exceeding two atmospheres, and especially it cannot be commercially used in a liquefied form.

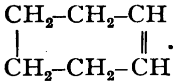
Other hydrocarbons having the general formula, C_nH_{2n-2}, may be divided into four classes:

1. True homologues of acetylene, or open-chain compounds containing one triple union, as allylene,

$$CH_3 - C \equiv CH.$$

2. Open-chain compounds having two double unions, as propadien, $CH_2 = C = CH_2$.

3. Cyclic compounds having one double union, as cyclohexene,



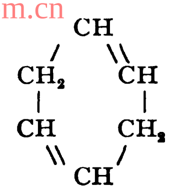
4. Dicyclic compounds. To this class, dekahydronaphthalene, $C_{10}H_{18}$, probably belongs, but very few hydrocarbons of the class are known.

Nomenclature. — In the official nomenclature, hydrocarbons of the marsh-gas series and saturated cyclic compounds take names ending in *-ane*, the latter with the prefix cyclo. Compounds having double unions take names ending in *-ene*, or, if two or three double unions are present, the endings *-diene*, *-triene*, etc. Thus $CH_2=C=CH_2$ is propadiene. Compounds having triple unions take names ending in *-ine;* thus $CH=C-CH_3$ is, officially, propine. Unfortunately, the official names are not always used, and it is often necessary to learn two names for the same compound.

Series C_nH_{2n-4} and C_nH_{2n-6}. — Hydrocarbons with open chains, and containing less hydrogen than the members of the acetylene series, present few facts that are new in principle or that require consideration here. In general the instability of the compounds increases with the decrease of hydrogen. Some compounds containing several triple unions are so unstable as to be explosive. All of the compounds under consideration are spoken of as *unsaturated*, because they all add bromine, iodine or the halogen acids directly, without loss of hydrogen. They are converted, by such addition, into substitution products of the marsh-gas series.

Hydrocarbons containing the group CH adjacent to a triple union give precipitates with an ammoniacal solution of a silver or of a cuprous salt. No other hydrocarbons do this.

Terpenes. — A considerable number of hydrocarbons which have the formula $C_{10}H_{16}$ are found in nature or are obtained from natural products. These bodies are unsaturated, as shown by their conduct toward permanganate, and by the fact that they combine directly with one or two molecules of hydrochloric acid. That they never combine with more than two molecules of the halogen acids proves that they are cyclic compounds. (Why?) It was formerly supposed that the terpenes are in most cases derivatives of cyclohexadiene,



having two hydrogen atoms replaced by a methyl and a propyl group respectively and with the double unions in varying positions. The more recent work with the group indicates that some of the hydrocarbons contain a double ring and that in others the double unions may be in the side chain rather than in the nucleus. It is probable, also, that some of them contain a ring of five carbon atoms, instead of six. A number of chemists are at present engaged with the study of the group, which presents unusual difficulties. Very few syntheses have thus far been effected in the group; and until some of the more important terpenes or their derivatives are prepared artificially, the knowledge of these compounds is likely to continue unsatisfactory. The study of the group has been rendered more complex and difficult by the ease with which many members of it undergo molecular rearrangements, sometimes with radical changes of structure.

Laboratory Exercises.

1. Preparation of acetylene by two or three different methods. Preparation of copper acetylide.

2. Preparation of pinene hydrochloride $C_{10}H_{17}Cl$, or "artificial camphor" from turpentine.

CHAPTER VII.

BENZENE SERIES, C_nH_{2n-6}.

Aliphatic and Aromatic Compounds. — The compounds of this series, and other compounds which are closely related to them, present so many peculiarities that it has been customary to separate organic compounds, for discussion, into two great classes, the "aliphatic,"* or open-chain compounds, and the "aromatic" compounds. Formerly very few reactions were known by which it was possible to pass from one class of compounds to the other in such a manner as to establish any relation in the structure of the compounds involved. A considerable number of such reactions are now known, and with their discovery some of the reasons for a separate treatment have disappeared. During recent years, also, the knowledge of cyclic compounds which are more closely related in their general properties to the aliphatic than to the aromatic compounds has been greatly extended. (See alicyclic compounds, pp. 117, 445.) More than one-half of the carbon compounds at present known belong to the aromatic series.

No hydrocarbon nor any derivative of a hydrocarbon having the distinctive properties of this group, and containing less than six carbon atoms, is known. Also it is possible, by means of simple and well understood reactions, to break down very many compounds of the series in such a manner as to obtain compounds containing only six carbon atoms in the molecule. The simplest hydrocarbon which can be obtained by reactions of this kind is benzene, C_6H_6.

We must look upon benzene, therefore, as the simplest and typical compound of the series, and the determination of its

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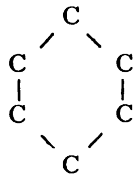
* The word aliphatic is derived from the Greek ἄλειφαρ, fat, and is based on the fact that the more important acids obtained from the natural fats are derivatives of the marsh-gas hydrocarbons.

structure has acquired a very unusual interest. It must be admitted, at the outset, that this problem has not yet received a complete and satisfactory solution, though there is probably no question of structure which has received more careful attention and certainly none to which a more thorough discussion has been given.

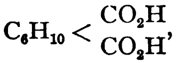
Structure of Benzene. — The more important experimental facts upon which the discussion of the structure of benzene must be based are as follows:

1. Benzene, and all substances which can be considered as belonging to its class, contain at least six carbon atoms. This has been already stated above.

2. By the action of chlorine or bromine on benzene in direct sunlight, benzenehexachloride, $C_6H_6Cl_6$, or benzenehexabromide, $C_6H_6Br_6$, is formed. Reducing agents cause the addition of six hydrogen atoms to some derivatives of benzene. Thus the hydrogen evolved from boiling amyl alcohol and sodium converts benzoic acid, $C_6H_5CO_2H$, into hexahydrobenzoic acid, $C_6H_{11}CO_2H$. Since chlorine, bromine or hydrogen would convert an open-chain compound into a derivative of hexane, C_6H_{14}, these facts can be satisfactorily explained only by supposing that benzene contains a ring of carbon atoms, thus:

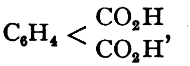


The truth of this conclusion has been further demonstrated by the preparation of hexahydroisophthalic acid,



$$C_6H_{10} < \begin{matrix} CO_2H \\ CO_2H \end{matrix},$$

both by reactions which show that it is a derivative of cyclohexane, and by the reduction of isophthalic acid,



$$C_6H_4 < \begin{matrix} CO_2H \\ CO_2H, \end{matrix}$$

which is a simple derivative of benzene.

3. There is but one mono-substitution product of benzene with a given substituent; i.e., there is but one mono-bromobenzene, C_6H_5Br; but one mononitrobenzene, $C_6H_5NO_2$; but one benzoic acid, $C_6H_5CO_2H$.

That four different hydrogen atoms in the benzene molecule may be replaced by the same group, and that the four compounds obtained are not different but identical, have been demonstrated as follows:

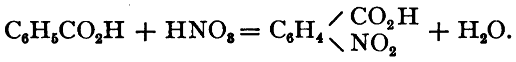
Phenol on treatment with phosphorus pentabromide gives monobrombenzene.

$$C_6H_5OH + PBr_5 = C_6H_5Br + POBr_3 + HBr.$$

Monobrombenzene gives, with sodium and carbon dioxide, sodium benzoate.

$$C_6H_5Br + CO_2 + 2Na = C_6H_5CO_2Na + NaBr.$$

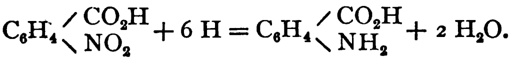
Benzoic acid gives, with nitric acid, three different nitrobenzoic acids.



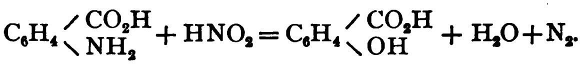
$$C_6H_5CO_2H + HNO_3 = C_6H_4 \begin{matrix} \diagup CO_2H \\ \diagdown NO_2 \end{matrix} + H_2O.$$

These nitrobenzoic acids can be readily separated by crystallization of their barium salts. Each gives by reduction a different amino-benzoic acid.

$$C_6H_4 \begin{matrix} \diagup CO_2H \\ \diagdown NO_2 \end{matrix} + 6H = C_6H_4 \begin{matrix} \diagup CO_2H \\ \diagdown NH_2 \end{matrix} + 2H_2O.$$

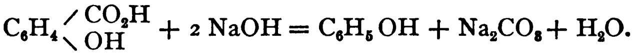


Each amino-benzoic acid gives with nitrous acid a different hydroxy-benzoic acid.



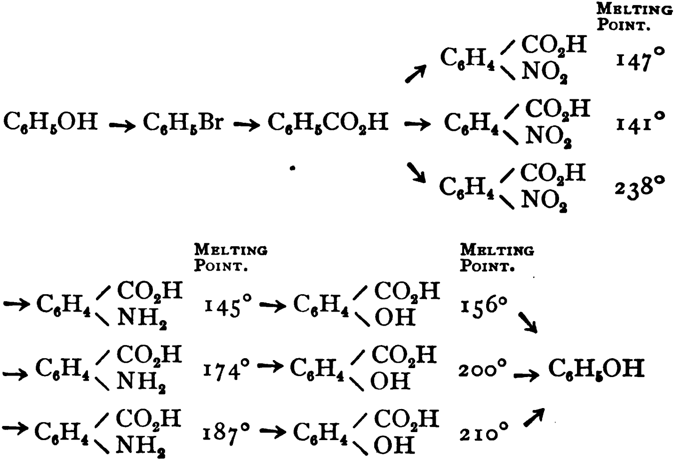
$$C_6H_4\left\langle\begin{matrix}CO_2H\\NH_2\end{matrix}\right. + HNO_2 = C_6H_4\left\langle\begin{matrix}CO_2H\\OH\end{matrix}\right. + H_2O + N_2.$$

It is evident that in each hydroxy-benzoic acid the hydroxyl group must replace a different hydrogen atom of the benzene molecule; and, also, since the carboxyl occupies the place of the original hydroxyl of the phenol, that each of these hydrogen atoms is different from that replaced by the original hydroxyl. Now each hydroxy-benzoic acid, on distilling with soda-lime, gives a phenol identical in every respect with the original phenol.



$$C_6H_4\left\langle\begin{matrix}CO_2H\\OH\end{matrix}\right. + 2\,NaOH = C_6H_5OH + Na_2CO_3 + H_2O.$$

The relations will, perhaps, be clearer from the following diagram:

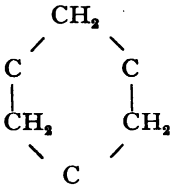


$$\begin{tikzcd}[column sep=small]
 & & & & & \text{MELTING POINT.} \\
 & & & & C_6H_4\left\langle\begin{matrix}CO_2H\\NO_2\end{matrix}\right. & 147^\circ \\
C_6H_5OH \arrow[r] & C_6H_5Br \arrow[r] & C_6H_5CO_2H \arrow[r] & {} \arrow[ur] \arrow[r] \arrow[dr] & C_6H_4\left\langle\begin{matrix}CO_2H\\NO_2\end{matrix}\right. & 141^\circ \\
 & & & & C_6H_4\left\langle\begin{matrix}CO_2H\\NO_2\end{matrix}\right. & 238^\circ
\end{tikzcd}$$

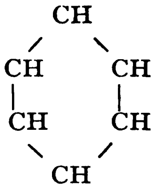
$$\begin{tikzcd}[column sep=small]
 & & \text{MELTING POINT.} & & & \text{MELTING POINT.} & \\
{} \arrow[r] & C_6H_4\left\langle\begin{matrix}CO_2H\\NH_2\end{matrix}\right. & 145^\circ \arrow[r] & C_6H_4\left\langle\begin{matrix}CO_2H\\OH\end{matrix}\right. & & 156^\circ \arrow[dr] & \\
{} \arrow[r] & C_6H_4\left\langle\begin{matrix}CO_2H\\NH_2\end{matrix}\right. & 174^\circ \arrow[r] & C_6H_4\left\langle\begin{matrix}CO_2H\\OH\end{matrix}\right. & & 200^\circ \arrow[r] & C_6H_5OH \\
{} \arrow[r] & C_6H_4\left\langle\begin{matrix}CO_2H\\NH_2\end{matrix}\right. & 187^\circ \arrow[r] & C_6H_4\left\langle\begin{matrix}CO_2H\\OH\end{matrix}\right. & & 210^\circ \arrow[ur] &
\end{tikzcd}$$

The proof given under 4 below, that when one hydrogen atom in benzene has been replaced by some atom or group there are two pairs of hydrogen atoms symmetrically placed with regard to that group, completes the demonstration that the relation of any hydrogen atom in benzene to the rest of the molecule is like that of every other.

There are only two arrangements which meet the requirements that benzene must contain a ring of six carbon atoms, and that the hydrogen atoms must be symmetrically placed. These are:



and



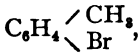
4. With a given pair of substituents there may be three, and only three, bisubstitution products of benzene; thus there are three bibrombenzenes, $C_6H_4Br_2$, three nitrobenzoic acids, $C_6H_4\begin{matrix}\diagup CO_2H\\ \diagdown NO_2\end{matrix}$, etc.

The first part of the statement is, of course, demonstrated by the existence of three isomeric bisubstitution products of benzene, three illustrations of such cases being given above.

That there are only three bisubstitution products in a given case is demonstrated as follows:—

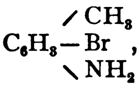
One of the brombenzoic acids, $C_6H_4\begin{matrix}\diagup CO_2H\\ \diagdown Br\end{matrix}$, gives by treatment with nitric acid two different nitrobrombenzoic acids, $C_6H_3\begin{matrix}\diagup CO_2H\\ -Br\\ \diagdown NO_2\end{matrix}$, but these give by reduction the same aminobenzoic acid, $C_6H_4\begin{matrix}\diagup CO_2H\\ \diagdown NH_2\end{matrix}$. Since the nitrobrombenzoic acids are different, the nitro groups in them must occupy different positions with regard to the bromine, but the two positions must bear the same relation to the carboxyl.

Further, there is a methylbrombenzene,



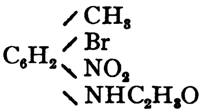
$C_6H_4\left\langle\begin{matrix}CH_3\\Br\end{matrix}\right.$

, which gives, by oxidation, the same brombenzoic acid mentioned above, and which must, therefore, have the bromine and methyl in the same relation as the bromine and carboxyl in the brombenzoic acid. The same methylbrombenzene can be prepared from a given methylaminobrombenzene



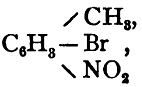
$C_6H_3\begin{matrix}/CH_3\\-Br\\ \backslash NH_2\end{matrix}$

, by replacing the amino group with hydrogen. The acetyl derivative of this methylaminobrombenzene gives with nitric acid a nitro derivative,



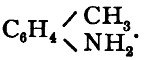
$C_6H_2\left\langle\begin{matrix}CH_3\\Br\\NO_2\\NHC_2H_3O\end{matrix}\right.$

, this, by elimination of the acetamino-group, a methyl nitrobrombenzene,



$C_6H_3\begin{matrix}/CH_3\\-Br\\ \backslash NO_2\end{matrix}$

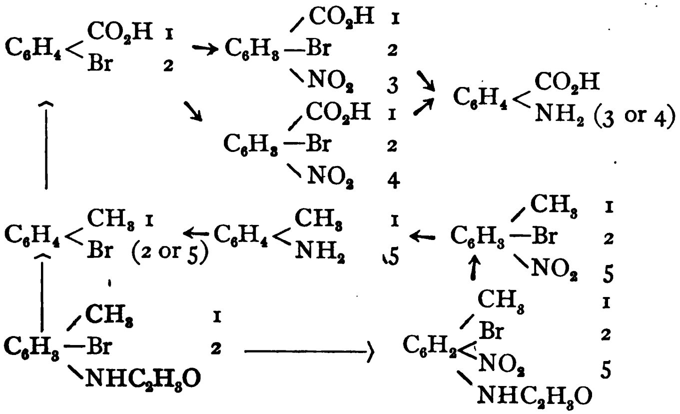
, and this, by reduction, a methyl, aminobenzene,



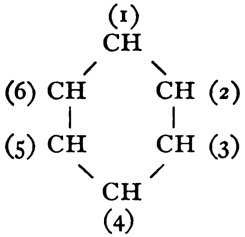
$C_6H_4\left\langle\begin{matrix}CH_3\\NH_2\end{matrix}\right.$

. The last compound gives, by replacement of the amino group with bromine, the same methylbrombenzene as that mentioned above. Since the nitro group must replace a different hydrogen atom from that originally replaced by the bromine, there must be a pair of hydrogen atoms symmetrically placed with regard to the methyl. As the position of the bromine atom does not correspond to that of either one of the first pair of symmetric hydrogen atoms, it follows that there are two pairs of such hydrogen atoms.

The relations will be clearer from a study of the following diagram.*



The conditions outlined last, that benzene contains two pairs of hydrogen atoms symmetrically related to an initial hydrogen atom, and a third which bears a different relation from that of either of the four, together with the conditions previously named, can only be met by supposing that benzene contains a ring of six CH groups, thus:



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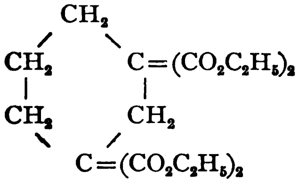
[*] The numbers are used here in purely consecutive order, so that it may be easier to follow the positions. The brombenzoic acid is the meta compound, and the nitro group enters in the ortho position with regard to the carboxyl.

In this formula it will be seen that positions 2 and 6, and also 3 and 5, are symmetrically placed with regard to 1, while the position 4 is different from any other.

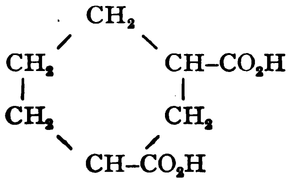
Such positions as 1.2 or 2.3 or 1.6 are called *ortho;* 1.3 or 2.4 or 2.6 are called *meta;* and 1.4 or 2.5 or 3.6 are called *para.* The practical means used to distinguish the different positions will be discussed below.

5. The order of the carbon atoms in benzene is the same as in cyclohexane; that is, ortho carbon atoms are adjacent, meta carbon atoms are separated by one carbon atom, and para carbon atoms are separated by two carbon atoms.

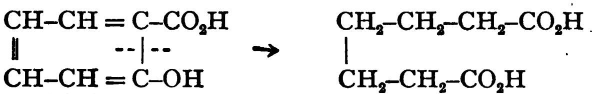
Isophthalic acid, $C_6H_4 < \begin{matrix} CO_2H \\ CO_2H \end{matrix}$, which is a meta compound, gives hexahydroisophthalic acid, $C_6H_{10} < \begin{matrix} CO_2H \\ CO_2H \end{matrix}$, by reduction. When the ethyl ester of pentanetetracarboxylic acid, $CH_2 < \begin{matrix} CH_2CH(CO_2C_2H_5)_2 \\ CH_2CH(CO_2C_2H_5)_2 \end{matrix}$, is treated with sodium ethylate and methylene iodide CH_2I_2 1.1, 3.3 cyclohexane tetracarboxylic ester,



is formed, and this gives by saponification and heating (see p. 251) the same hexahydroisophthalic acid,

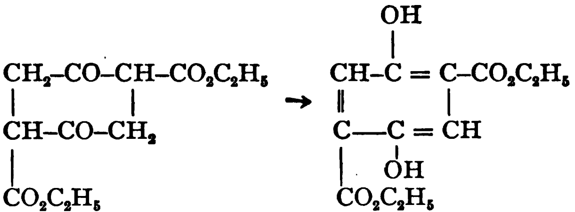


which is formed by the reduction of isophthalic acid. A similar proof for the ortho position is given by the formation of pimelic acid by the reduction of salicylic acid, thus:



Salicylic acid. Pimelic acid.

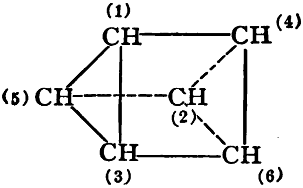
For the para position a similar proof of the order of the carbon atoms is given by the formation of the ethyl ester of dihydroxyterephthalic acid when succinylo-succinic ester is treated with bromine:



Succinylo-succinic ester. Dihydroxyterephthalic ester.

Ladenburg's Prism Formula.—The conclusion of this paragraph is of especial interest from its bearing on Ladenburg's prism formula, which was looked upon with favor by many chemists a few years ago.

This is,



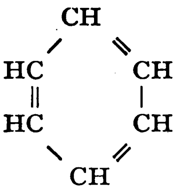
Since the position 4 is the only one which is different from all others in its relation to position 1, it must be para to that position. In the same way positions 2, 5, and 3, 6, must be para. Further, since the positions 1, 3, admit of three other positions (4 or 6, 2 and 5) with regard to them, these positions must be meta (see below). 1, 2 and 1, 6, must for a similar reason be ortho. But it is impossible that a compound of this structure should give, by reduction, a ring containing six carbon atoms in which the atoms 1 and 2 are adjacent. The formula is therefore impossible, although it explains satisfactorily most of the compounds which contain the benzene nucleus.

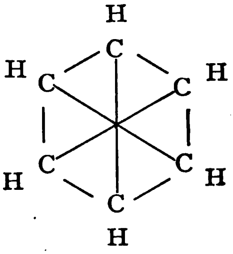
6. The low molecular volume of benzene has been taken as evidence that benzene must contain nine single unions between the carbon atoms. (Schiff, *Ann. Chem.* (Liebig), **220**, 303.) The effect of the cyclic structure in causing a decrease of the molecular volume appears, however, to have been overlooked in the discussion (see p. 42).

The molecular refraction corresponds to that which we should expect for a compound with three double unions. (Brühl, *Zeit. phys. Chem.* **1**, 348.)

The heat of combustion is given as 776 Cal. by Berthelot, as 779.5 Cal. by Stohmann. The heat of combustion of 72 grams of carbon is 8.08 × 72 = 581.8 Cal.; that of 6 grams of hydrogen is 34.2 × 6 = 205.2, or together 72 grams of carbon and 6 grams of hydrogen would give 787. Cal. This gives a heat of formation for benzene of + 7.5 or + 11. Cal. The heat of formation of cyclohexane, C_6H_{12}, is + 59 Cal. (see p. 85). It seems, therefore, when we consider the heats of formation of ethane and ethylene (p. 81), as well as those of cyclohexane and of benzene, that the results are more consistent with the supposition of three double unions than with that of nine single unions. Thomsen, *Thermochem Untersuch.* 4, 6, and Dieffenbach, *Zeit. phys. Chem.* **5**, 574, however, draw an opposite conclusion.

Formula of Benzene. — When an attempt is made to assign a formula to benzene which shall agree with all of the facts given above, and also give expression to the quadrivalence of carbon, very grave difficulties are encountered. The two formulae which at present receive serious consideration are those of Kekulè and of Claus. The latter is known in some of its interpretations as the "diagonal" and as the "centric" formula.


Kekulè.


Claus.

Many variations of these formulae have been given; but they all come back, for their essential basis, to one or the other form. See Kekulè, *Ann. Chem.* (Liebig), **162**, 86; Baeyer, *Ber. chem. Ges.* **23**, 1272; Sachse, *Ber. chem. Ges.* **21**, 2530; *Zeit. phys. Chem.* **11**, 214; Armstrong, *Proc. Chem. Soc.* (London) *1890*, 101; Marsh, *Phil. Magazine*, **26**, 426 (1888); Collie, *J. Chem. Soc.* (London), **71**, 1013 (1897); Erlenmeyer, Jr. *Ann. Chem.* (Liebig), **316**, 57; C. Graebe, *Ber. chem. Ges.* **35**, 526 (1902).

The most serious objection to Kekulè's formula is that it represents positions 1, 2 and 1, 6 as different, the carbon atoms being connected by a double union in the one case and by a single union in the other. To meet this difficulty Kekulè supposed (*Ann. Chem.* (Liebig), **162**, 86), that the union between the carbon atoms is dynamic rather than static, and that the double and single unions may be considered as continually shifting their places. (See also Knorr, *Ann. Chem.* (Liebig), 279, 196.) A second objection to the formula is that it represents benzene as an unsaturated compound, while in all of its most common and important characteristics it conducts itself as a saturated body. Also, as soon as two hydrogen atoms have been added to benzene or to any of its derivatives they conduct themselves in all respects as other unsaturated compounds do. Benzene and its derivatives with saturated side-chains are without effect on a cold dilute solution of potassium permanganate while dihydrobenzene, tetrahydrobenzene and their derivatives reduce such a solution instantly.

The objection to the diagonal or centric formula is that if the carbon atoms are considered as in the same plane the diagonal unions must, for geometric reasons, be different from the other unions. Even if a stereomeric form * be found which meets this objection, the chemical evidence given demonstrates that when hydrogen is added to benzene or its derivatives it is the centric unions which are dissolved, while what may be called the cyclic unions always remain.

The choice among these formulae and their interpretations must be considered at present as uncertain. The proper attitude for a beginner, at least, is to look upon the question as still an open one, and gradually to gather in his mind evidence as to one view or another till enough has been accumulated for an independent judgment.

So far as the practical investigation of aromatic compounds is concerned, the questions last discussed have little interest. In the study of these compounds the cyclic unions are the only ones which require consideration, for almost all cases.

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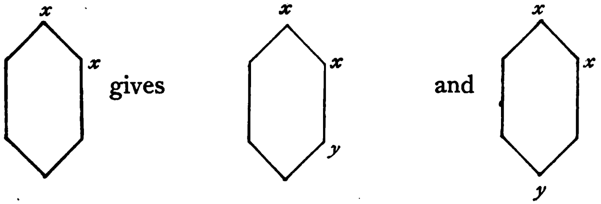
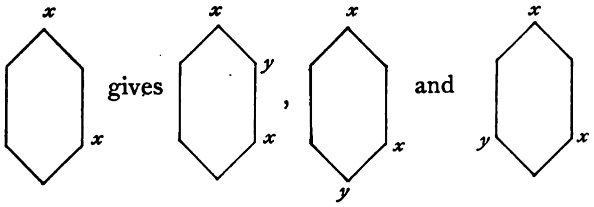
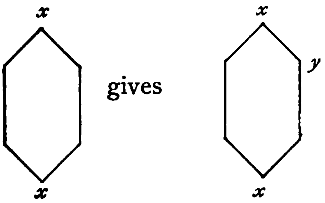
* That is, an arrangement of the atoms in space.

Ortho, Meta, and Para Positions. — In the study of these compounds, a question of great practical importance is as to how the three positions, ortho, meta, and para may be distinguished. An answer to this question, based upon the relation to derivatives of cyclohexane, has already been given. It is possible, however, to secure an entirely independent answer from the study of "aromatic" compounds alone.

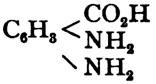
If we suppose two hydrogen atoms in benzene to be replaced by the same atom or group, examination of the resulting formulae will show that with an ortho compound a third substituent may give two isomeric compounds, with a meta compound three such compounds may be obtained, while a para compound gives only one. Thus:







The following is an illustration of how these principles are applied. There are six diaminobenzoic acids,

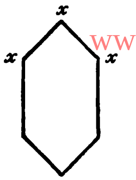


$$C_6H_3 < \begin{matrix} CO_2H \\ NH_2 \\ NH_2 \end{matrix}$$

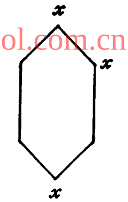
Two of these give a diaminobenzene, $C_6H_4(NH_2)_2$ melting at 102°. This must be the ortho compound. Three give a diaminobenzene melting at 63°, evidently meta; and one gives para-diaminobenzene melting at 140°.

Having once determined to which class, ortho, meta, or para, a few derivatives of benzene belong, the structure of other compounds can be determined by conversion into one of the known forms, or by conversion of a known form into the compound whose structure is to be determined. Thus the conversion of nitro compounds into amino compounds, of amino compounds into halogen derivatives, hydroxyl compounds and acids, and of halogen derivatives into hydrocarbons and acids, may be readily effected by reactions which will be given later. In such reactions it is assumed, of course, that the new group takes the position of the old one. In some cases, and especially in fusions with caustic potash, this is not always true; and at one time some confusion arose from this cause, so that in the period 1867 to 1880 it is necessary to notice, in using the literature, that ortho and meta compounds are often interchanged.

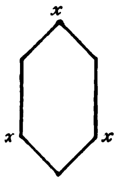
Trisubstitution products of benzene having adjacent groups are called "neighboring," or "vicinal;" those having two groups adjacent and a third separated from them are "asymmetric;" while those with three separated groups are called "symmetric."



Neighboring (Vicinal) (v)



Asymmetric (a)



Symmetric (s)

BENZENE SERIES.

		BOILING POINT.	MELTING POINT.	SPECIFIC GRAVITY.
Benzene	C_6H_6	80.36°	5.42°	0.8736 $\frac{20^\circ}{4}$
Toluene	$C_6H_5CH_3$	111.°		0.8656 "
o-Xylene	$C_6H_4\left\langle\begin{matrix}CH_3\ (1)\\ CH_3\ (2)\end{matrix}\right.$	141.9°	—28°	0.8766 "
m-Xylene	$C_6H_4\left\langle\begin{matrix}CH_3\ (1)\\ CH_3\ (3)\end{matrix}\right.$	139.2°	—54°	0.8655 "
p-Xylene	$C_6H_4\left\langle\begin{matrix}CH_3\ (1)\\ CH_3\ (4)\end{matrix}\right.$	138.°	15°	0.8635 "
Ethyl benzene	$C_6H_5C_2H_5$	136.5°	—	0.8683 "
Hemellithene **v-Trimethyl benzene**	$C_6H_3\begin{matrix}/CH_3\ (1)\\ —CH_3\ (2)\\ \backslash CH_3\ (3)\end{matrix}$	175°	—	—
Pseudocumene **asym. Trimethyl benzene**	$C_6H_3\begin{matrix}/CH_3\ (1)\\ —CH_3\ (2)\\ \backslash CH_3\ (4)\end{matrix}$	169.8°		0.8787 "
Mesitylene **sym. Trimethyl benzene**	$C_6H_3\begin{matrix}/CH_3\ (1)\\ —CH_3\ (3)\\ \backslash CH_3\ (5)\end{matrix}$	164.5°	—	0.8694 $\frac{9.8^\circ}{4}$
Cumene **Isopropyl benzene**	$C_6H_5CH\left\langle\begin{matrix}CH_3\\ CH_3\end{matrix}\right.$	153°	—	0.8629 $\frac{20^\circ}{4}$
Durene **1.2.4.5. Tetra methyl benzene**	$C_6H_2(CH_3)_4$	190°—194°	80°	—
Cymene **p. Methylisopropyl benzene**	$C_6H_4\begin{matrix}/CH_3 & (1)\\ \backslash CH\left\langle\begin{matrix}CH_3\\ CH_3\end{matrix}\right. & (4)\end{matrix}$	175°	—	0.8564 "

Only the most important hydrocarbons are given in this table. Many others are known.

Benzene.* — C_6H_6. This hydrocarbon was first discovered by Faraday in 1825, in the liquid formed by compression of

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* Benzene and "benzine" are totally different substances. See p. 73.

oil-gas. It was first isolated from coal-tar by A. W. Hofmann in 1845. It is formed by passing acetylene, C_2H_2, through a hot tube. It may also be prepared by heating benzoic acid, $C_6H_5CO_2H$, with soda-lime:

$$C_6H_5CO_2Na + NaOH = Na_2CO_3 + C_6H_6.$$

Many of the earlier researches with benzene were carried out with material obtained in this manner. At present benzene is obtained almost exclusively from coal-tar. It is separated partly by fractional distillation, partly by shaking it with a small amount of concentrated sulphuric acid to remove thiophene, C_4H_4S, and finally by freezing it and pouring off the liquid portion. It boils at 80.4°, melts at 5.4° and has a specific gravity of $0.8736^{20}_{4}{}^{\circ}$. It is now prepared from coal-tar in very large quantities for use in manufacturing dye-stuffs and other commercial products. It is also present in illuminating gas, and is a very important constituent in giving illuminating power to the gas. Recently, benzene and some of its homologues have been found in considerable quantities in California petroleum.

Benzene and its homologues and related compounds are, undoubtedly, not present in the coal, but are formed during its distillation, very much as benzene is formed from acetylene. The same compounds are formed when almost any kind of organic matter is subjected to destructive distillation at a high temperature.

Toluene, $C_6H_5CH_3$, is also present in considerable quantities in coal-tar, and is easily prepared from that source. It is also formed by the action of sodium on a mixture of monobrombenzene and methyl iodide.

$$C_6H_5Br + CH_3I + 2\ Na = C_6H_5CH_3 + NaBr + NaI.$$

This is known as Fittig's synthesis; by its means the real nature of the hydrocarbon was first demonstrated.

Toluene, and its derivatives in which only the hydrogen of the side-chain (i.e. methyl) has been replaced, may be oxidized to benzoic acid, $C_6H_5CO_2H$. The formation of acids by the oxidation of side-chains is one of the special characteristics of the series. A similar oxidation of side-chains has been very rarely observed in the case of aliphatic compounds.

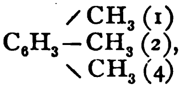
Xylenes, $C_6H_4<\begin{matrix}CH_3\\CH_3\end{matrix}$. All three of the xylenes are contained in the coal-tar and may be prepared from it. If the fraction containing the xylenes is boiled for some time with dilute nitric acid (Sp. gr. 1.15), the ortho- and paraxylenes are mostly oxidized to acids which may be removed by washing with a solution of sodium hydroxide. A residue is left which consists mainly of metaxylene. On the other hand, by shaking with concentrated sulphuric acid, ortho- and paraxylene are left undissolved, while metaxylene is converted into a sulphonic acid, $C_6H_3\begin{matrix}\diagup (CH_3)_2\\ \diagdown SO_3H\end{matrix}$. For further details of the separations, the student is referred to larger works.

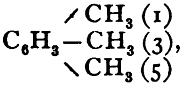
By oxidation the xylenes give ortho-, meta-, and paratoluic acids, $C_6H_4\begin{matrix}\diagup CH_3\\ \diagdown CO_2H\end{matrix}$, and by further oxidation, (ortho) phthalic acid, (meta) isophthalic acid and (para) terephthalic acid,

$$C_6H_4\begin{matrix}\diagup CO_2H\\ \diagdown CO_2H\end{matrix}.$$

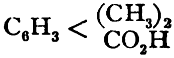
Ethyl benzene, $C_6H_5C_2H_5$, gives by oxidation benzoic acid, $C_6H_5CO_2H$; and this is typical of aromatic hydrocarbons with side-chains containing more than one carbon atom.

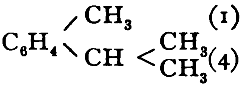
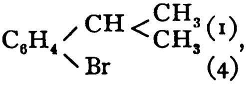
This principle may be used for the determination of structure. What must be the structure of a hydrocarbon, C_9H_{12}, which gives isophthalic acid by oxidation? What structures are possible for a hydrocarbon, $C_{10}H_{14}$, which gives paratoluic acid by oxidation?

Pseudocumene,  $C_6H_3\begin{matrix}/CH_3\ (1)\\ -CH_3\ (2)\\ \backslash CH_3\ (4)\end{matrix}$, is found in coal-tar, and has been prepared both from monobrommetaxylene and monobromparaxylene by treatment with methyl iodide and sodium. How does this demonstrate its structure?

Mesitylene,  $C_6H_3\begin{matrix}/CH_3\ (1)\\ -CH_3\ (3)\\ \backslash CH_3\ (5)\end{matrix}$, is found in coal-tar, but is most easily prepared by mixing acetone with concentrated sulphuric acid, and distilling the mixture. (See p. 191.)

$$3CH_3COCH_3 - 3H_2O = C_9H_{12}.$$

Since the reaction is most easily explained by supposing that the positions of the methyl groups are symmetrical in mesitylene, the fact that mesitylenic acid,  $C_6H_3 < \begin{matrix}(CH_3)_2\\ CO_2H\end{matrix}$ gives metaxylene by distillation with soda-lime was, at one time, used to prove that the methyl groups in that hydrocarbon are in the meta position. More satisfactory demonstrations are now known for the positions of the groups.

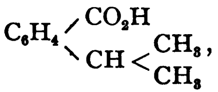
Cymene,  $C_6H_4\begin{matrix}/CH_3\ \ (1)\\ \backslash CH < \begin{matrix}CH_3\\ CH_3\end{matrix}(4)\end{matrix}$, is most easily prepared by warming camphor, $C_{10}H_{16}O$, with phosphorus pentoxide. It is formed, also, by the action of sodium, parabromisopropyl benzene,  $C_6H_4\begin{matrix}/CH < \begin{matrix}CH_3\\ CH_3\end{matrix}(1)\\ \backslash Br\ \ (4)\end{matrix}$, and methyl iodide.

Cymene is also formed by the action of chlorine on pinene (from turpentine).

$$\underset{\text{Turpentine.}}{C_{10}H_{16}} + 2Cl = \underset{\text{Cymene.}}{C_{10}H_{14}} + 2HCl.$$

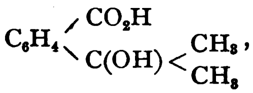
The preparation of cymene from camphor and from turpentine has given it an unusual interest; but the relation, in structure, to these compounds is not as close as was formerly supposed.

Cymene gives by oxidation, according to the agents used or the conditions, paratoluic, terephthalic, cuminic,



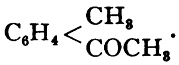
$$C_6H_4\begin{matrix}\diagup CO_2H \\ \diagdown CH<\begin{matrix}CH_3\\CH_3\end{matrix}\end{matrix},$$

hydroxyisopropyl benzoic,



$$C_6H_4\begin{matrix}\diagup CO_2H \\ \diagdown C(OH)<\begin{matrix}CH_3\\CH_3\end{matrix}\end{matrix},$$

acids, or paratolyl-methyl ketone,



$$C_6H_4<\begin{matrix}CH_3\\COCH_3\end{matrix}.$$

Preparation of Hydrocarbons. — The hydrocarbons of this series are prepared:

1. From coal-tar.
2. By treating a mixture of a halogen derivative of an aromatic hydrocarbon with an *alkyl** iodide and sodium. (Fittig's synthesis.)

$$\underset{\text{Brombenzene.}}{C_6H_5Br} + \underset{\text{Methyl iodide.}}{CH_3I} + 2Na = \underset{\text{Toluene.}}{C_6H_5CH_3} + NaBr + NaI.$$

---

* The name "*alkyl*" is used for univalent hydrocarbon radicals, especially for those of the aliphatic series, as methyl, CH_3, ethyl, C_2H_5, etc. Vorländer, *J. pr. Chem.* **59**, 247, proposes to call the latter *alphyls*, and similar radicals of the aromatics series, as C_6H_5, *aryls*.

This reaction is especially useful in the determination of constitution.

3. By treating an aromatic hydrocarbon with an alkyl chloride or bromide and aluminium chloride. (Friedel and Craft's reaction.)

$$C_6H_6 + CH_3\,Cl + AlCl_3 = C_6H_5CH_3 + HCl + AlCl_3.$$

A compound of the hydrocarbon with aluminium chloride, $C_6H_5AlCl_2$, appears to be formed at first, and this reacts with the alkyl chloride. Accompanying the synthesis the reverse reaction may occur, as xylene may be converted into toluene, or toluene into benzene.

4. By distilling acids or sulphonic acids with soda-lime, or by heating sulphonic acids with dilute sulphuric or concentrated hydrochloric acid.

$$\underset{\text{Sodium benzoate.}}{C_6H_5CO_2Na} + NaOH = \underset{\text{Benzene.}}{C_6H_6} + Na_2CO_3.$$

$$\underset{\text{Benzene sulphonic acid.}}{C_6H_5SO_3H} + HCl + H_2O = C_6H_6 + H_2SO_4 + HCl.$$

5. By the elimination of an amino group after formation of a diazo compound or hydrazine. (See pp. 459 and 477.)

$$\underset{\text{Aniline sulphate.}}{(C_6H_5NH_2)_2H_2SO_4} + 2HNO_2 = \underset{\text{Benzene diazonium sulphate.}}{(C_6H_5N_2)_2SO_4} + 4\,H_2O.$$

$$(C_6H_5N_2)_2SO_4 + 2C_2H_5OH = 2C_6H_6 + 2N_2 + H_2SO_4 + \underset{\text{Aldehyde.}}{2C_2H_4O.}$$

6. By distilling a phenol with zinc dust.

$$\underset{\text{Phenol.}}{C_6H_5OH} + Zn = C_6H_6 + ZnO.$$

General Characteristics. — While halogen derivatives, sulphonic acids and nitro compounds are formed from aliphatic hydrocarbons only with considerable difficulty, similar derivatives of "aromatic" hydrocarbons are easily prepared:

$$C_6H_6 + Br_2 = C_6H_5Br + HBr.$$

Brombenzene.

$$C_6H_6 + H_2SO_4 = C_6H_5SO_3H + H_2O.$$

Benzene sulphonic acid.

$$C_6H_6 + HNO_3 = C_6H_5NO_2 + H_2O.$$

Nitrobenzene.

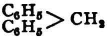
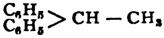
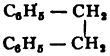
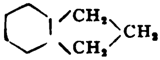
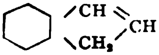
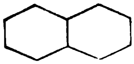
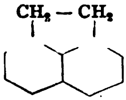
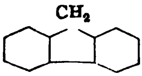
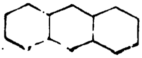
The resulting compounds, too, are much more stable in the aromatic series. While ethyl bromide, C_2H_5Br, and similar compounds will react easily with ammonia and slowly with silver nitrate and water, the bromine of brombenzene, C_6H_5Br, is not at all affected by these reagents. The ease with which homologues of benzene are oxidized, and the resulting products, have already been considered.

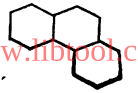
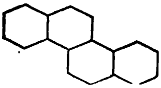
Laboratory Exercises.

1. Preparation of benzene, toluene, and xylene by the fractionation of the light oil of coal-tar.
2. Preparation of benzene from benzoic acid.
3. Preparation of toluene from monobrombenzene or of *p*-xylene from bibrombenzene.
4. Preparation of cymene from camphor.
5. Preparation of paratoluic and terephthalic acids from cymene.
6. Preparation of mesitylene from acetone.
7. Preparation of phenol from salicylic and from *p*-hydroxybenzoic acids.

CHAPTER VIII.

HYDROCARBONS RELATED TO BENZENE.

		Boiling Point.	Melting Point.	Specific Gravity.
Styrene	$C_6H_5CH = CH_2$	144°	—	$0.9074\frac{20^\circ}{4}$
Phenyl acetylene	$C_6H_5C \equiv CH$	141.6°	—	$0.9295\frac{20^\circ}{4}$
Diphenyl	$C_6H_5 - C_6H_5$	254°	70.5	$0.9919\frac{73^\circ}{4}$
Diphenyl methane	 $\begin{matrix}C_6H_5\\C_6H_5\end{matrix} > CH_2$	261°	27°	$1.0008\frac{26^\circ}{4}$
1, 1 Diphenyl ethane	 $\begin{matrix}C_6H_5\\C_6H_5\end{matrix} > CH - CH_3$	286°	—	
1, 2 Diphenyl ethane	 $\begin{matrix}C_6H_5 - CH_2\\ \vert \\C_6H_5 - CH_2\end{matrix}$	284°	52°	1.0423(52°)
Triphenyl methane	$(C_6H_5)_3CH$	359°	92°	—
Hexaphenylethane	$(C_6H_5)_3C - C(C_6H_5)_3$	—	—	—
Hydrindene		176°	—	0.957(15°)
Indene		180°	—	1.040(15°)
Naphthalene		218.12°	80.06°	1.1517(15°)
Acenaphtene		277.5°	103°	1.0300(103°)
Fluorene		294°	113°	—
Anthracene		351°	213°	—

Phenanthrene		340°	99°	—
Chrysene		448°	250°	—

Very many hydrocarbons are known which contain one or more benzene nuclei combined with groups derived from other hydrocarbons or with each other in a great variety of ways. Some of the typical combinations are given in the table. Only a few of these need receive further discussion here.

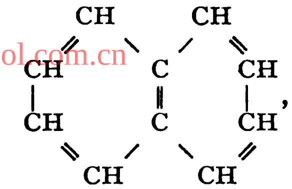
Triphenylmethane $(C_6H_5)_3CH$ is prepared by Friedel and Craft's reaction from benzene and chloroform.

$$3\ C_6H_6 + CHCl_3 + AlCl_3 = (C_6H_5)_3CH + 3\ HCl + AlCl_3$$

The hydrocarbon is of especial interest because of its relation to rosaniline and to phenol phthaleïn (p. 263).

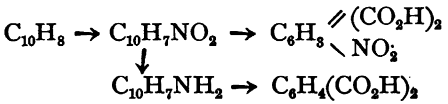
Hexaphenylethane, $(C_6H_5)_3C-C(C_6H_5)_3$, is formed when triphenylchlormethane, $(C_6H_5)_3CCl$, is allowed to act upon zinc, sodium or mercury with careful exclusion of air. When exposed to air or oxygen it is at once converted into ditriphenylmethylperoxide, $(C_6H_5)_3C-O-O-C(C_6H_5)_3$. It combines directly with iodine to form triphenyliodomethane. This extraordinary conduct led, at first, to the belief that the hydrocarbon was triphenylmethyl, $(C_6H_5)_3C$, and contained an unsaturated carbon atom. The unusual properties of hexaphenylethane are best explained by supposing that it readily dissociates, forming two molecules of triphenylmethyl. (Gomberg, *J. Am. Chem. Soc.* **22**, 757; **23**, 496; **24**, 597. Tschitschibabin, Ber. **40**, 367.)

Naphthalene,



is found in considerable quantity in coal-tar. Its structure is demonstrated as follows:

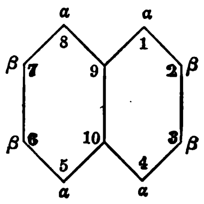
Naphthalene gives, on treatment with nitric acid, nitro-naphthalene; and this, on oxidation, yields a nitrophthalic acid, $C_6H_3\begin{cases} CO_2H & (1) \\ CO_2H & (2) \\ NO_2 & (3) \end{cases}$. If nitronaphthalene is reduced, it gives amino-naphthalene, and this, on oxidation, gives phthalic acid.



$$\begin{tikzcd} C_{10}H_8 \arrow[r] & C_{10}H_7NO_2 \arrow[r] \arrow[d] & C_6H_3\begin{cases}(CO_2H)_2 \\ NO_2\end{cases} \\ & C_{10}H_7NH_2 \arrow[r] & C_6H_4(CO_2H)_2 \end{tikzcd}$$

Since amino derivatives of benzene do not lose the amino group on oxidation without its replacement by some other atom or group, these results can only be explained by supposing that naphthalene contains two complete benzene nuclei. This is only possible if two of the carbon atoms are common to the two nuclei.

Naphthalene gives two mono substitution products, *α* and *β*. The numbering of the carbon atoms is as follows:

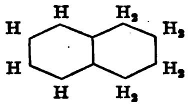


The positions are named as follows:

1.2 = ortho.
1.3 = meta.
1.4 = para.
1.5 = ana.
1.6 = epi.
1.7 = kata.
1.8 = peri.
2.6 = amphi.
2.7 = pros.

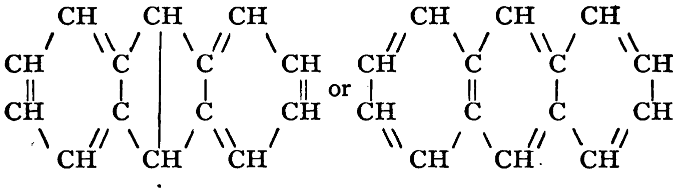
These terms are seldom used and are given only for reference.

Naphthalene gives by reduction tetrahydronaphthalene.

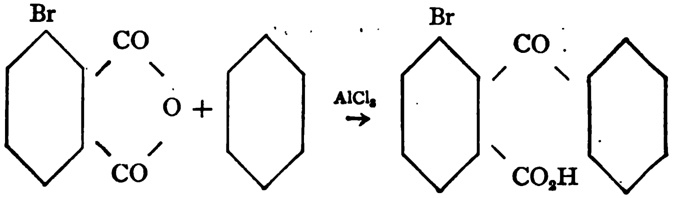


The derivatives of this hydrocarbon have an especial interest, because those having a substituent in the benzene nucleus show the aromatic characteristics, while those with substituents in the reduced nucleus are similar in their properties to the derivatives of cyclohexane. To the latter class of compounds the name "alicyclic" has been given. (Bamberger.)

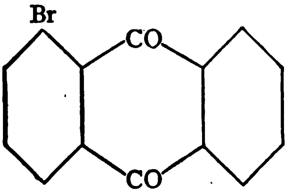
Anthracene,



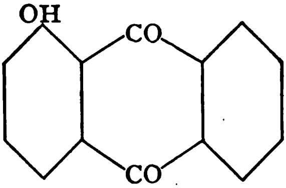
This hydrocarbon is found in small amounts in coal-tar, and is separated for use in the manufacture of alizarin, or "Turkey red." When a solution of bromphthalic anhydride in benzene is treated with aluminium chloride, brombenzoyl benzoic acid is formed.



The brombenzoyl benzoic acid gives, with concentrated sulphuric acid at 180°, bromanthraquinone,



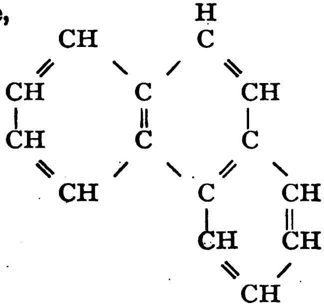
The bromanthraquinone yields, on fusion with caustic potash, hydroxyanthraquinone,



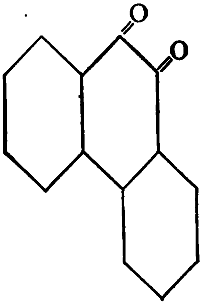
and this, by oxidation, gives phthalic acid. Since the benzene nucleus of the phthalic acid is the one represented at the right in the formulae it follows that the carbonyl (CO) groups of anthraquinone are ortho in that nucleus as well as in the other. Since further, anthraquinone has been reduced to anthracene by distillation with zinc dust, the structure of the latter is established.

The most characteristic reaction of anthracene is the formation of anthraquinone, $C_6H_4{<}\genfrac{}{}{0pt}{}{CO}{CO}{>}C_6H_4$, from it by direct oxidation. For the nomenclature of anthracene derivatives see p. 214.

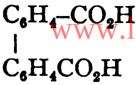
Phenanthrene,



is also found in coal-tar. It is formed when a mixture of diphenyl, $C_6H_5C_6H_5$, and ethylene are passed through a heated tube. It gives, on oxidation, but less easily than anthracene, phenanthraquinone,

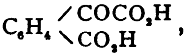


,

and this, on further oxidation, diphenyl-dicarboxylic acid, 
$$\begin{array}{l} C_6H_4\text{–}CO_2H \\ | \\ C_6H_4CO_2H \end{array}$$
, in which both carboxyl groups are ortho to the point of union between the two phenyl groups. This gives proof of the structure.

Laboratory Exercises.

1. Preparation of triphenyl methane.
2. Oxidation of naphthalene to phthalonic acid,


$$C_6H_4\begin{array}{l} \diagup COCO_2H \\ \diagdown CO_2H \end{array},$$

by means of potassium permanganate in alkaline solution and further oxidation of the latter to phthalic acid by manganese dioxide in acid solution.

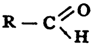
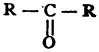
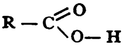
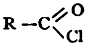
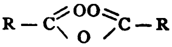
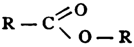
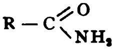
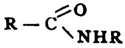
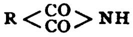
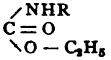
3. Preparation of anthracene from anthraquinone by distilling with zinc dust.

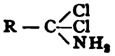
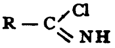
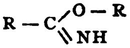
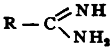
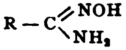
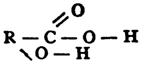
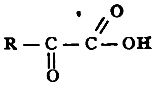
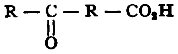
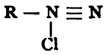
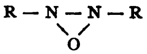
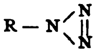
4. Determination of the per cent of anthracene in a sample of coal-tar.

CHAPTER IX.

CLASSIFICATION OF DERIVATIVES OF THE HYDROCARBONS.

Most carbon compounds containing other elements than hydrogen may be conveniently considered as derivatives of hydrocarbons. The following list of the more important fundamental forms of such derivatives is given for convenience of reference:—

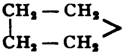
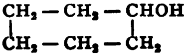
Alcohols and phenols	$R-O-H$
Ethers	$R-O-R$
Aldehydes	 $R-C\begin{array}{l}/\!\!/O\\ \backslash H\end{array}$
Ketones	 $R-\underset{\overset{\Vert}{O}}{C}-R$
Acids	 $R-C\begin{array}{l}/\!\!/O\\ \backslash O-H\end{array}$
Acid chlorides	 $R-C\begin{array}{l}/\!\!/O\\ \backslash Cl\end{array}$
Acid anhydrides	 $R-C\begin{array}{l}/\!\!/O\ O\backslash\!\!\backslash\\ \backslash\ O\ /\end{array}C-R$
Esters	 $R-C\begin{array}{l}/\!\!/O\\ \backslash O-R\end{array}$
Amides	 $R-C\begin{array}{l}/\!\!/O\\ \backslash NH_2\end{array}$
Alkyl amides	 $R-C\begin{array}{l}/\!\!/O\\ \backslash NHR\end{array}$
Imides	 $R<\begin{array}{c}CO\\ CO\end{array}>NH$
Urethanes	 $\begin{array}{l}/NHR\\ C=O\\ \backslash O-C_2H_5\end{array}$
Cyanides or nitriles	$R-C\equiv N$
Isocyanides or isonitriles	$R-N=C$

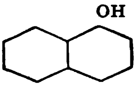
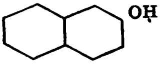
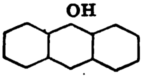
Cyanates	$R-O-C\equiv N$
Isocyanates	$R-N=C=O$
Thiocyanates	$R-S-C\equiv N$
Isothiocyanates or mustard oils	$R-N=C=S$
Amide chlorides	
Imide chlorides	
Imidoesters	
Amidines	
Amidoximes	
Hydroxy acids	
Ketonic acids	
or	 $R-\underset{\underset{O}{\parallel}}{C}-R-CO_2H$
Halogen compounds	RCl, RBr, etc.
Nitro compounds	$R-NO_2$
Amines	RNH_2, R_2NH, etc.
Diazo compounds	 $R-\underset{\underset{Cl}{\vert}}{N}\equiv N$
or	$R-N=N-Cl$
Hydrazo compounds	$R-NH-NH-R$
Azo compounds	$R-N=N-R$
Diazoamino compounds	$R-N=N-NHR$
Aminoazo compounds	$R-N=N-R-NH_2$
Hydroxyazo (or "oxyazo") compounds	$R-N=N-R-OH$
Azoxy compounds	
Hydrazines	$R-NH-NH_2$
Hydrazones	$R-NH-N=C<^{R}_{R}$
Diazoimides	

Oximes or isonitroso compounds	$\genfrac{}{}{0pt}{}{R}{R}>C=N-O-H$
Nitroso compounds	$R-NO$
or	$R-\underset{R\diagup\quad}{N}-NO$
Mercaptans or thioalcohols	$R-S-H$
Sulphides or sulphur ethers	$R-S-R$
Sulphoxides	$\genfrac{}{}{0pt}{}{R}{R}>S=O$
Sulphones	$\genfrac{}{}{0pt}{}{R}{R}>S\genfrac{}{}{0pt}{}{\diagup\!\!\diagup O}{\diagdown\!\!\diagdown O}$
Sulphonium bases	$\begin{matrix}R\diagdown\\ R-\\ R\diagup\end{matrix}S-O-H$
Sulphonic acids	$R-SO_2-O-H$
Sulphochlorides	$R-SO_2Cl$
Sulphamides	$R-SO_2NH_2$
Sulphinides	$R<\genfrac{}{}{0pt}{}{CO}{SO_2}>NH$

CHAPTER X.

ALCOHOLS AND PHENOLS.

	MELTING POINT.	BOILING POINT.	SP. GR.
CH_3OH Methyl alcohol (Methanol)	—	66°	0.8142 (0°)
CH_3CH_2OH Ethyl alcohol (Ethanol)	— 112°	78.3°	0.806 (0°)
$CH_3CH_2CH_2OH$ Propyl alcohol (Propanol-1)	—	97.4°	0.8205 (0°)
$CH_3CHOHCH_3$ Isopropyl alcohol (Propanol-2)	—	82.1°	0.798 (4°)
$CH_3(CH_2)_2CH_2OH$ Primary butyl alcohol (Butanol-1)	—	117°	0.824 (0°)
$CH_3CH_2CHOHCH_3$ Secondary butyl alcohol (Butanol-2)	—	99°	0.827 (0°)
$\begin{matrix}CH_3\\CH_3\end{matrix}>CH-CH_2OH$ Isobutyl alcohol (2-Methylpropanol-1)	—	106°	0.817 (0°)
$\begin{matrix}CH_3\\CH_3\end{matrix}>COH-CH_3$ Tertiary butyl alcohol (2-Methylpropanol-2)	25°	83°	0.780 (26°)
$CH_3(CH_2)_3CH_2OH$ Normal amyl alcohol (Pentanol-1)	—	137°	0.830 (0°)
$\begin{matrix}CH_3\\CH_3\end{matrix}>CH-CH_2CH_2OH$ Isoamyl alcohol (3-Methylbutanol-1)	—	130°	0.825 (0°)
$CH_2OHCH(CH_3)CH_2CH_3$ Active amyl alcohol (2-Methylbutanol-1)	—	128.7°	0.833 (0°)
$CH_3(CH_2)_{14}CH_2OH$ Cetyl alcohol	50°	344°	0.817 (50°)
$CH_2=CH-CH_2OH$ Allyl alcohol (1-Propenol-3)	—	96.6°	0.871 (0°)
$CH_3CH=CH-CH_2OH$ Crotyl alcohol (2-Butenol-4)	—	117°	0.873 (0°)
$CH_2=CH-CH_2CH_2OH$ 1-Butenol-4	—	113°	0.864 (0°)
 Cyclobutanol	—	123°	—
 Cyclopentanol	—	139°	0.940 (21°)
 Cyclohexanol	17°	160.5°	—

$\left.\begin{array}{l}CH_2-CH_2-CH_2\\ \vert\\ CH_2-CH_2-CH_2\end{array}\right>CHOH$	Cycloheptanol	—	184°	0.960 (15°)
$CH\equiv C-CH_2OH$	Propargyl alcohol (1-Propinol-3)	— 17°	114°-115°	0.971 (20°)
$C_{10}H_{17}OH$	Borneol	204°	212°	0.808 (210°)
C_6H_5OH	Phenol	43°	181.5°	1.0597 (32.9°
$C_6H_4<\begin{matrix}CH_3 & 1\\ OH & 2\end{matrix}$	*o*-Cresol	30°	190.8°	1.0578 (0°)
$C_6H_4<\begin{matrix}CH_3 & 1\\ OH & 3\end{matrix}$	*m*-Cresol	4°	202.8°	1.0498 (0°)
$C_6H_4<\begin{matrix}CH_3 & 1\\ OH & 4\end{matrix}$	*p*-Cresol	36°	201.8°	1.0522 (0°)
$C_6H_5-CH_2OH$	Benzyl alcohol (Phenmethylol)	—	204.7°	1.0628 (0°)
$C_6H_3\left\{\begin{array}{ll}CH_3 & 1\\ OH & 2\\ CH<\begin{matrix}CH_3\\ CH_3\end{matrix} & 4\end{array}\right.$	Carvacrol	0°	237°	0.978 (20°)
$C_6H_3\left\{\begin{array}{ll}CH_3 & 1\\ OH & 3\\ CH<\begin{matrix}CH_3\\ CH_3\end{matrix} & 4\end{array}\right.$	Thymol	51.5°	231.8°	0.940 (65°)
	α Naphthol	96°	279°	1.224 (4°)
	β Naphthol	122°	285°	1.217 (4°)
	Anthranol	163°-170°	—	—
$\begin{array}{l}CH_2OH\\ \vert\\ CH_2OH\end{array}$	Glycol (Ethanediol)	11.5°	197°	1.125 (0°)
$CH_2OHCHOHCH_2OH$	Glycerol (Propanetriol)	20°	290°	1.262 (17.5°)
$\begin{array}{l}CHOH-CH_2OH\\ \vert\\ CHOH-CH_2OH\end{array}$	(*d* + *l*) Erythrol (Butanetetrol)	72°	—	—
$\begin{array}{l}CHOH-CH_2OH\\ \vert\\ CHOH-CH_2OH\end{array}$	*i*-Erythrol (Butanetetrol)	126°	—	—
$CH_2OH(CHOH)_4CH_2OH$	Mannite (Hexanehexol)	166°	—	—
$CH_2OH(CHOH)_4CH_2OH$	Dulcite (Hexanehexol)	188.5°	—	1.466 (15°)
$CH_2OH(CHOH)_4CH_2OH$	Sorbite (Hexanehexol)	—	—	—

$C_6H_4<\begin{matrix}OH & 1\\ OH & 2\end{matrix}$	Pyrocatechol (Phendiol 1, 2)	104°	240°–245°	1.344
$C_6H_4<\begin{matrix}OH & 1\\ OH & 3\end{matrix}$	Resorcinol (Phendiol 1, 3)	119°	276.5°	1.272 (15°)
$C_6H_4<\begin{matrix}OH & 1\\ OH & 4\end{matrix}$	Hydroquinone (Phendiol 1, 4)	169°	—	—

The simplest derivatives of the hydrocarbons containing oxygen are the alcohols. They may be considered as derived from the hydrocarbons by the addition of an atom of oxygen, but their relation to the hydrocarbons is not so close as would appear from such a statement.

ALCOHOLS, $C_nH_{2n+2}O$.

Methyl Alcohol, CH_3OH, (**methanol**). This is the first and simplest of all the alcohols. It is formed, along with many other products, by the destructive distillation of wood; also by the destructive distillation of the residues from the spent liquors (*vinasse*) left when the molasses of beet sugar has been fermented for the production of alcohol. The crude product is separated from acetic acid by neutralization with milk of lime and distillation, and partly purified by fractional distillation. The still impure substance obtained in this way, and known as "wood-alcohol," is used for burning, as a solvent for shellac in making varnish, and otherwise as a substitute for ordinary alcohol. These uses depend, economically, on the tax paid upon ordinary alcohol, as ethyl alcohol can be manufactured more cheaply than "wood spirit." Methyl alcohol is also used in the manufacture of many aniline dyes and for syntheses of organic compounds.

The "wood spirit" contains acetone and other impurities which cannot be removed by fractional distillation. The pure alcohol can be obtained by converting it into some crystalline compound, the dimethyl ester of oxalic acid, $(CH_3)_2C_2O_4$, being most suitable, or into some derivative which has a different boiling point, as methyl benzoate, $C_6H_5CO_2CH_3$. From the oxalic ester the alcohol can be regenerated by boiling with water or ammonia.

$$\underset{\text{Methyl oxalate.}}{(CH_3)_2C_2O_4} + 2NH_3 + 2H_2O = 2CH_3OH + (NH_4)_2C_2O_4.$$

Calcium chloride crystallizes with methyl alcohol much as it does with water, and the compound may also be used to purify the alcohol. Methyl alcohol boils at 66° and has a specific gravity of 0.7931 at $\frac{15.6^\circ}{15.6^\circ}$.

In general properties methyl alcohol resembles ordinary (ethyl) alcohol. When taken internally it produces intoxication, and in larger doses acts as a poison. In solvent properties it stands between ethyl alcohol and water, substances which dissolve in water dissolving more easily in methyl alcohol than in ordinary alcohol.

Chemical Properties. — Sodium dissolves in methyl alcohol with evolution of hydrogen and formation of sodium methylate.

$$Na + CH_4O = CH_3ONa + H.$$

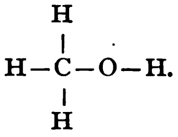
With the halogen acids it forms, more or less easily, monohalogen derivatives of methane, and water.

$$HI + CH_4O = \underset{\text{Methyl iodide.}}{CH_3I} + H_2O.$$

With other acids it yields compounds known as *esters* in which the hydrogen of the acid is replaced by methyl.

$$2CH_4O + H_2C_2O_4 = \underset{\substack{\text{Dimethyl ester}\\ \text{of oxalic acid.}}}{(CH_3)_2C_2O_4} + 2H_2O$$

These reactions demonstrate that one hydrogen atom of the alcohol is intimately associated with the oxygen atom, and that the same hydrogen atom conducts itself differently from the other three. These facts find their most natural expression in the formula,



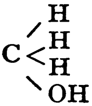
$$\begin{array}{c} H \\ | \\ H-C-O-H. \\ | \\ H \end{array}$$

This formula is confirmed by the synthesis of methyl alcohol when its esters are boiled with water, or when methyl iodide is heated with water.

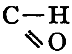
$$(CH_3)_2C_2O_4 + 2HOH = 2\,CH_3OH + H_2C_2O_4$$
$$CH_3I + HOH = CH_3OH + HI.$$

Since other alcohols conduct themselves in the same manner, it is assumed that they all contain the hydroxyl group, and an alcohol is defined, structurally, as a hydrocarbon in which a hydrogen atom has been replaced by a hydroxyl group. In formulae and in their reactions the alcohols are analogous to the metallic hydroxides. An important difference is found in the practically instantaneous reaction between metallic hydroxides and acids, and the comparative slowness of the similar reaction between alcohols and acids. This is probably due to the greater dissociation of metallic hydroxides, most of the alcohols undergoing, apparently, very slight dissociation into the alkyl radical and hydroxyl ions. The reaction with sodium indicates that alcohols also dissociate into the group R–O– and hydrogen ions, but this dissociation, too, must be trifling, since the alcoholates are decomposed by a very small amount of water, even in the presence of large amounts of the alcohol.

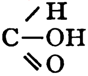
By oxidation under appropriate conditions methyl alcohol gives formaldehyde, formic acid and carbonic acid.



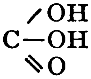
Methyl alcohol.



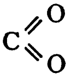
Formaldehyde.



Formic acid.



Carbonic acid.



Carbon dioxide.

The structure of these compounds will be considered later.

Effect of the Hydroxyl Group. — It should be noticed that the presence of the hydroxyl group in methyl alcohol completely changes its character as compared with that of methane. While the hydrocarbons of the marsh-gas series are affected only by the most vigorous chemical agents, the alcohols are easily oxidized and react readily with acids and other substances. The presence of the oxygen decreases the stability of the molecule. Not only is this true in general, but that portion of the molecule containing the oxygen is most easily affected in the case of the homologous alcohols of the series, and so becomes the point of attack for oxidation and for the action of other agents.

Ethyl Alcohol, C_2H_5OH **(ethanol).** Ordinary alcohol, or ethyl alcohol is, at present, always prepared, commercially, by the fermentation of solutions containing sugar. The two cheapest sources of such solutions are the molasses from which crystallizable sugars have been removed, and solutions prepared from substances which contain starch, especially from Indian corn and potatoes. Liquors containing alcohol, such as wine, cider and perry, are obtained by the fermentation of the juices of grapes, apples and pears, which contain sugar, but these liquors are rarely used as a source of pure alcohol.

In the manufacture of alcohol from corn, which is most used in America, the grain is ground and put into steel boilers with water. It is then heated for about an hour to a temperature of 155° by means of steam under pressure. The pressure within the boiler is then rapidly reduced to a point considerably below atmospheric pressure. By this means the water within the starch granules is converted into steam, and the covering of the granules is thoroughly ruptured, exposing the starch freely to the subsequent action of the diastase. The temperature, also, is rapidly reduced to 65°–70°. One part of malt * is then added for about ten parts of the meal. At that temperature, the diastase converts the starch, $(C_6H_{10}O_5)_n$, very rapidly into maltose, $C_{12}H_{22}O_{11}$, (about 80 per cent), and dextrin, $C_{36}H_{62}O_{31}$, (about 20 per cent). The solution is then rapidly cooled, mixed with yeast, and diluted till a solution containing about ten per cent of saccharine matter, and at a temperature of 18°–22°, is obtained. The yeast (*saccharomyces*) causes the transformation of the maltose and of a part of the dextrin into alcohol and carbon dioxide.

$$C_{12}H_{22}O_{11} + H_2O = 4\,C_2H_6O + 4\,CO_2.$$

The reaction is exothermic, and the temperature of the solution rises 10°–12° during the three or four days of fermentation. For the successful growth of the yeast, there must be present, besides the saccharine matter, a small amount of nitrogenous material and of inorganic salts, especially phosphates and sulphates.

Theories of Fermentation. — In the earlier theories of fermentation it was supposed (Liebig) that the action was due

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* Malt is prepared by moistening barley and leaving it in a warm place till it sprouts. The grain is then dried and the sprouts are removed. During germination the barley develops a soluble nitrogenous compound called diastase. Diastase belongs to the class of bodies known as soluble ferments or *enzymes* (p.517).

to a catalytic effect of some substance present in the fermenting solution, the general notion being that substances in a state of decomposition may, by their presence, cause the decomposition of other bodies. Later, the work of Pasteur established, apparently, that the fermentation is inseparably connected with the life of the yeast. Recently it has been shown (Buchner), however, that by pressing yeast to remove the liquid which adheres to it, grinding it with sand to break the cell walls, and pressing it again, a liquid may be obtained which, after filtering through porous porcelain to remove all live yeast cells, will still cause a rapid transformation of glucose into alcohol and carbon dioxide. It seems, therefore, that the yeast contains a soluble ferment (enzyme), which transforms sugar, much as diastase transforms starch. This soluble ferment is called *zymase*, but it has not yet been isolated. Such action is called catalytic because the ferment itself appears to remain unchanged, and a very small amount of it may transform large quantities of the bodies affected. The chemical action involved is very poorly understood, but similar transformations undoubtedly play a very important part in digestion and in other life processes.

By the processes described above, a liquid is obtained containing about five per cent of alcohol by weight. This is subjected to fractional distillation.

The "beer" is pumped continuously into a still, so constructed with a series of shelves that the alcohol-free liquors, called "slop," run away at the bottom, while an alcohol of 60 to 80 per cent distills continuously from the top. This crude alcohol is diluted and filtered through charcoal to remove corn oil, esters and other substances which impart to it a disagreeable taste and odor. It is then distilled a second time, and most of the alcohol is obtained with a strength of

90 to 95 per cent. Toward the end of this distillation a mixture of higher alcohols known as fusel oil passes over. This contains chiefly isoamyl alcohol with small amounts of isobutyl and propyl alcohols. The first portions of the distillate also contain impurities, chiefly aldehyde, formed by the oxidation of a little of the alcohol as it passes through the charcoal.

Absolute Alcohol. — Since the boiling point of pure alcohol is higher than that of an alcohol containing a small amount of water, it is impossible to obtain alcohol free from water by distillation alone. The mixture having the lowest boiling point contains 96 per cent of alcohol by weight, or 97.4 per cent by volume, and this mixture is the extreme limit which can be reached by fractional distillation. (*J. Am. Chem. Soc.* 23, 463.) The last portions of water may be removed by boiling strong alcohol with lime, for some hours, in a flask, connected with an upright condenser. The removal of the last traces of water is extremely difficult, and even "absolute" alcohol usually contains one-half of a per cent of water.

Ethyl alcohol boils at 78.3° and has a specific gravity of 0.76326 $\left(\frac{15^\circ}{4^\circ}\right)$. It solidifies at -112°.

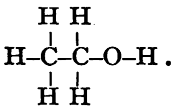
Determination of Alcohol. — In mixtures containing nothing but alcohol and water, the amount of alcohol present is determined by means of the specific gravity and by reference to tables. The specific gravity must be determined accurately by means of a picnometer, a Westphal balance, or a sensitive spindle. The alcohol must be brought to the temperature for which the table is constructed, or a temperature correction must be applied. In the case of liquors containing other substances than alcohol and water, the alcohol must be separated by distillation. The distillate is then usually made up to the original volume and the specific gravity determined.

Physiological Effects. — Taken internally, ethyl alcohol lowers the temperature of the body 0.5 to 2 degrees. In moderate amounts it is mostly oxidized in the body and appears to play essentially the same part as other foods in producing bodily warmth and energy. In larger amounts, or in concentrated form, it is a poison.

"Proof spirit" in America is made the basis for taxation, and contains 50 per cent of alcohol, by volume.

Uses. — Ethyl alcohol burns with a non-luminous, smokeless flame, and hence is used for heating purposes in alcohol lamps. It dissolves very many organic substances, and is used in making varnishes, in preparing tinctures for medicinal use, in the manufacture of ether, and in a great variety of ways in chemical factories and in laboratories.

Chemical Properties. — In most of its chemical properties it resembles methyl alcohol. The formation of sodium ethylate, C_2H_5ONa, or ethyl iodide C_2H_5I, and of esters containing the group C_2H_5, as ethyl acetate, $C_2H_5\ C_2H_3O_2$, can be satisfactorily explained only by assuming the structure, C_2H_5OH. In detail this becomes,

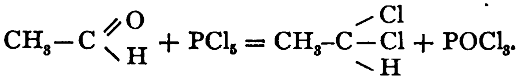


$$\begin{array}{ccccccccc} & & H & & H & & & & \\ & & | & & | & & & & \\ H & - & C & - & C & - & O & - & H. \\ & & | & & | & & & & \\ & & H & & H & & & & \end{array}$$

This view of its structure is further supported by a study of the oxidation products of ethyl alcohol. These are aldehyde, C_2H_4O, and acetic acid, $C_2H_4O_2$.

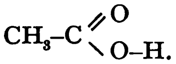
Since sodium acetate, $NaC_2H_3O_2$, gives methane, CH_4, and sodium carbonate when heated with soda-lime, acetic acid must contain a methyl (CH_3) group, and the same group must be present in acetaldehyde and in ethyl alcohol.

Acetaldehyde, C_2H_4O, gives, on treatment with phosphorus pentachloride, ethylidene chloride, CH_3CHCl_2, and hence probably contains an oxygen atom which is doubly united with a carbon atom.



$$CH_3-C\begin{array}{l}/\!\!/ O\\ \diagdown H\end{array} + PCl_5 = CH_3-C\begin{array}{l}\diagup Cl\\ -Cl\\ \diagdown H\end{array} + POCl_3.$$

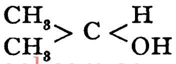
It is noticeable that in the oxidation of ethyl alcohol to aldehyde and acetic acid the portion of the molecule attacked is that portion already containing the hydroxyl group. Since ethyl alcohol is a saturated body, we may suppose that oxygen enters between a hydrogen and a carbon atom giving, at first, a compound $CH_3-C\begin{array}{l}\diagup OH\\ -OH.\\ \diagdown H\end{array}$ Compounds of this character, having two hydroxyl groups combined with a single carbon atom, are unstable, or, in most cases, incapable of existence. The aldehyde, $CH_3-C\begin{array}{l}/\!\!/ O\\ \diagdown H\end{array}$, which results on loss of water, takes, on further oxidation, a second oxygen atom between the carbon and hydrogen atoms, giving acetic acid,

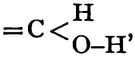


$$CH_3-C\begin{array}{l}/\!\!/ O\\ \diagdown O-H.\end{array}$$

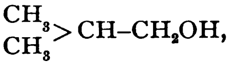
The oxidation products of ethyl alcohol here given are typical for all alcohols containing the group $-CH_2OH$.

Normal Propyl Alcohol, $CH_3-CH_2-CH_2OH$, (**propanol–1**), is found in small amount in fusel oil. Its structure is established by a study of its oxidation products, which are propionic aldehyde, $CH_3CH_2C\begin{array}{l}/\!\!/ O\\ \diagdown H\end{array}$, and propionic acid, $CH_3CH_2C\begin{array}{l}/\!\!/ O\\ \diagdown OH\end{array}$. (See also p. 62.)

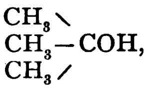
Isopropyl Alcohol,  $\begin{matrix}CH_3\\CH_3\end{matrix}> C <\begin{matrix}H\\OH\end{matrix}$, **(propanol–2)**, is prepared by boiling isopropyl iodide, CH_3CHICH_3, with water. It has also been prepared by the reduction of acetone, CH_3COCH_3, by means of sodium amalgam. The structure is established by the preparation from acetone and by the fact that acetone gives a mixture of acetic and formic acids by oxidation.

Isopropyl alcohol is also called secondary propyl alcohol and is the simplest of the secondary alcohols. The secondary alcohols contain the group  $=C<\begin{matrix}H\\O\text{–}H\end{matrix}$, and give, on oxidation, ketones, containing the group $=C=O$, and then acids with a smaller number of carbon atoms.

There are four butyl alcohols possible, and all of them are known.

Primary Normal Butyl Alcohol, $CH_3CH_2CH_2CH_2OH$, **(butanol–1)**, and **Primary Isobutyl Alcohol,**  $\begin{matrix}CH_3\\CH_3\end{matrix}>CH\text{–}CH_2OH$, **methyl–2–propanol–1)**, give, by oxidation, aldehydes and acids, as do all primary alcohols.

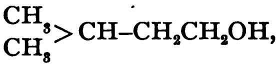
Secondary Normal Butyl Alcohol, $CH_3CHOHCH_2CH_3$, **(butanol–2)**, gives butanone, $CH_3COCH_2CH_3$, by oxidation and, on further oxidation, acetic acid.

Tertiary Butyl Alcohol,  $\begin{matrix}CH_3\diagdown\\CH_3\text{—}COH\\CH_3\diagup\end{matrix}$, **(methyl-2-propanol–2)**, gives acetone, CH_3COCH_3, and carbon dioxide by oxidation. The compound is usually called trimethyl carbinol, the name signifying that it is *carbinol* (methyl alcohol) in which three hydrogen atoms have been replaced by methyl.

The structure of these alcohols is established by their conduct when oxidized. As is apparent from the illustrations given, primary alcohols contain the group CH_2OH combined directly with a single carbon atom and give, by oxidation, aldehydes and acids containing the same number of carbon atoms as the alcohol. Secondary alcohols contain the group $>CHOH$ combined directly with two carbon atoms and give, by oxidation, ketones, and then an acid or acids with a smaller number of carbon atoms.

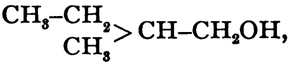
Tertiary alcohols contain the group $\equiv COH$ combined directly with three carbon atoms, and cannot be oxidized without loss of carbon.

Eight amyl alcohols, $C_5H_{11}OH$, are theoretically possible, and all have been prepared.* The only ones which have especial interest are the isoamyl alcohol,



$$\begin{matrix}CH_3\\ CH_3\end{matrix}\!\!>CH\text{–}CH_2CH_2OH,$$

(methyl-3-butanol-1) and active amyl alcohol,



$$\begin{matrix}CH_3\text{–}CH_2\\ CH_3\end{matrix}\!\!>CH\text{–}CH_2OH,$$

(methyl-2-butanol-1). Each of these is found in fusel oil, the pentyl alcohols of fusel oil consisting of 80–90 per cent of the first mixed with 10–20 per cent of the second. If the mixture is treated with hydrochloric acid gas and warmed, the isoamyl alcohol is converted into amyl chloride, $C_5H_{11}Cl$, more easily than the active amyl alcohol. In this manner a left-handed alcohol has been obtained having a rotation $[\alpha]_D = -5.90°$. (See p. 47.) The active alcohol has never been prepared artificially and no experiments furnishing direct evidence of its structure have been made.

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* The student will find it profitable to write the formulae and official names of these eight alcohols, and also to state their oxidation products.

Optical Activity.—A careful study of a very large number of active organic substances has shown, however, that in all cases where the structure of such substances has been determined, they contain at least one carbon atom which is combined with four different atoms or groups. Such a carbon atom is called an asymmetric carbon atom, since, if we consider the atoms or groups as situated in the direction of the axes of a tetrahedron with regard to the center of this carbon atom, two arrangements are possible. The two forms are related to each other in the same manner as an object and its image in a mirror. The relationship will be clear from a study of the accompanying figures.

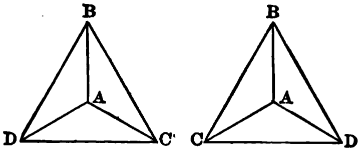


Fig. 25.

In crystallography two crystals related in this manner are said to be enantiomorphic.

Now, of the four possible primary amyl alcohols, only methyl-2-butanol-1, $\begin{matrix}CH_3CH_2\\ CH_3\end{matrix}>C<\begin{matrix}H\\ CH_2OH\end{matrix}$, contains an asymmetric carbon atom. It is assumed, therefore, that the active amyl alcohol possesses this structure.

Every active body may, theoretically, exist in at least two forms, a right-handed and a left-handed body. The right-handed body causes exactly the same degree of rotation to the right that the left-handed body does to the left. A mixture of equal parts of the two is inactive, and is often spoken of as a third form. The three forms are distinguished by the prefixes *d*, (for *dextro*) *l*, (for *laevo*) and *i* (for *inactive*).

The inactive mixture is also often called the *racemic* form, because the mixture of *d*- and *l*-tartaric acid, called racemic acid, is the first compound in which this relationship was discovered.

Enantiomorphic forms are identical in all of their physical and chemical properties except in their conduct toward polarized light, toward other optically active bodies, toward certain bacteria and ferments, and, in a few rare instances, in regard to their crystalline forms. A racemic form, however, often differs very considerably in its properties from its active components.

The synthesis from inactive materials of any compound having an asymmetric carbon atom always produces the racemic form; that is, a mixture is produced having the right-handed and left-handed bodies present in equal proportion. Three general methods have thus far been practically applied to the separation of such mixtures.

Separation of Racemic Compounds into their Components.— 1. In a very few instances the two active forms may be separated by crystallization. Thus a solution of the sodium ammonium salt of racemic acid, $(NaNH_4C_4H_4O_6)_2+2H_2O$, deposits, on evaporation, at temperatures below 28°, two kinds of crystals which may be separated mechanically. These crystals are enantiomorphic, and one set gives *d*-tartaric acid and the other *l*-tartaric acid.

2. Compounds of racemic bodies with active substances often deposit the compound with one of their active constituents more easily than with the other, and the two optical isomers may then be separated by fractional crystallization. The active bodies most often used for such purposes have been strychnine, cinchonine and brucine for acids, and tartaric acid for bases.

3. It has been found in many cases that micro-organisms cause the fermentation and destruction of one of the isomers in a racemic mixture, while the other is left unaltered or is little affected. As some one has put it, the organisms seem to have a better appetite for a right-handed body than for a left-handed one, or *vice-versa*. At basis, this method of separation is probably essentially the same as the second method, the peculiar action of the organisms being, doubtless, due to active compounds which they contain.

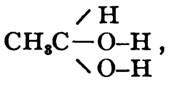
Pasteur effected the first separation of a racemic compound (racemic acid itself) into its optically active constituents, and he discovered all three of the general methods which are used in such separations. (*Ann. Chim. Phys.* [3] 24, 442; 28, 56; 38, 437. Pasteur's "Researches on the Molecular Asymmetry of Natural Organic Bodies," Alembic Club Reprints No. 14.)

A considerable number of alcohols of this series containing a larger number of carbon atoms are known, but there are no new facts of such general interest as to require their mention here.

Alcohols of the Ethylene Series, $C_nH_{2n-1}OH$.

As methylene, CH_2, the hypothetical first member of the ethylene series, appears to be incapable of a separate existence because of its tendency to polymerize or combine with itself, so the corresponding alcohol, $C{<}\begin{smallmatrix}H\\O-H\end{smallmatrix}$, is entirely unknown.

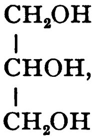
Vinyl Alcohol, $CH_2{=}C{<}\begin{smallmatrix}H\\O-H\end{smallmatrix}$ **(ethenol),** apparently exists in small amount in commercial ether, but it has never been prepared in a pure condition. Reactions which would naturally give vinyl alcohol always lead to the formation of aldehyde, $CH_3C\genfrac{}{}{0pt}{}{\diagup H}{\diagdown O}$, instead. It seems that the vinyl alcohol at first formed adds water, giving the compound,



$$CH_3C\begin{matrix}\diagup H\\ -O-H\\ \diagdown O-H\end{matrix},$$

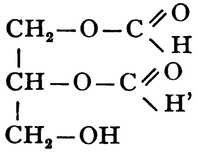
and the latter loses water again with the formation of aldehyde. Transformations of this sort evidently play an important part in the case of many compounds with a similar grouping, and have been a fruitful source of confusion and controversy. (See acetacetic ester and the alkyl nitro compounds.)

Allyl alcohol, $CH_2{=}CH-CH_2OH$ (**propenol-1**), is formed when glycerol is heated with oxalic acid. The oxalic acid decomposes at first into formic acid, $H-C\genfrac{}{}{0pt}{}{/\!\!/ O}{\diagdown OH}$, and carbon dioxide. The formic acid reacts with the glycerol,



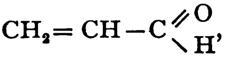
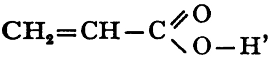
$$\begin{matrix}CH_2OH\\ |\\ CHOH\\ |\\ CH_2OH\end{matrix}$$

to give an ester, *diformin*,

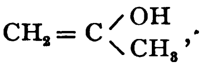


$$\begin{matrix}CH_2-O-C\genfrac{}{}{0pt}{}{/\!\!/ O}{\diagdown H}\\ |\\ CH-O-C\genfrac{}{}{0pt}{}{/\!\!/ O}{\diagdown H}\\ |\\ CH_2-OH\end{matrix}$$

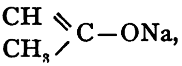
and the latter finally decomposes, giving formic acid, carbon dioxide and allyl alcohol. In an important sense the allyl alcohol may be considered as a reduction product of glycerol, oxalic or formic acid being the reducing agent.

Allyl alcohol boils at 96.6° and has a disagreeable odor. As a primary alcohol it may be oxidized to the aldehyde, acroleïn,  $CH_2=CH-C\begin{matrix}/\!\!/ O\\ \diagdown H\end{matrix}$, and to the acid, acrylic acid,  $CH_2=CH-C\begin{matrix}/\!\!/ O\\ \diagdown O-H\end{matrix}$, but, on account of its unsaturated character, much greater care is required for these operations than in the case of saturated alcohols. As an unsaturated compound, on careful oxidation with potassium permanganate it takes up two hydroxyl groups and is converted into glycerol. When treated with bromine, it is converted into 2.3 dibrom-propanol-1, $CH_2Br\ CHBr\ CH_2OH$. With phosphorus tribromide it gives allyl bromide, $CH_2=CH-CH_2Br$, and the latter takes up hydrobromic acid, giving trimethylene bromide, $CH_2BrCH_2CH_2Br$, or 1.3 dibrompropane.

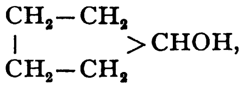
The isomeric unsaturated alcohol, propenol-2,



$$CH_2=C\begin{matrix}\diagup OH\\ \diagdown CH_3\end{matrix},$$

or β-allyl alcohol, appears to be incapable of existence, for reasons similar to those which cause vinyl alcohol to pass over into aldehyde. In the same manner β-allyl alcohol goes over into acetone, $CH_3-CO-CH_3$. On treatment with metallic sodium, however, acetone gives a compound having, apparently, the structure  $\begin{matrix}CH\\ CH_3\end{matrix}\begin{matrix}\diagdown\!\!\diagdown\\ \diagup\end{matrix}C-ONa$, which is to be looked upon as a derivative of the unsaturated alcohol. (Freer, *Ann. Chem.* (Liebig), 278, 116; *Am. Chem. Jour.*, 15, 582.)

Many alcohols of this series containing a greater number of carbon atoms are known, but need not be considered here.

Cyclic Alcohols. — Several cyclic alcohols which are isomeric with the unsaturated alcohols of this series are known. As with the cyclic hydrocarbons, those containing rings of five and six carbon atoms are most stable and of greatest interest. Cyclopentanol,  $\begin{array}{l}CH_2-CH_2\\ |\qquad\qquad\quad >CHOH\\ CH_2-CH_2\end{array}$, has already been referred to as a step in the preparation of cyclopentane (p. 84).

ALCOHOLS $C_nH_{2n-2}O$.

The alcohols of most interest having this general formula are a considerable number of compounds closely related to camphor and the terpenes.

Borneol, $C_{10}H_{18}O$, is formed by the reduction of camphor, $C_{10}H_{16}O$, by means of sodium and alcohol. The three forms, *d*-, *l*-, and *i*-borneol, have been prepared. It has the properties of a saturated secondary alcohol, and must, therefore, contain two rings of carbon atoms. Its structure follows from that of camphor (p. 195).

PHENOLS AND ALCOHOLS, $C_nH_{2n-6}O$.

Phenol, or **Carbolic acid**, C_6H_5OH. Derivatives of benzene and its homologues in which a hydrogen atom of the nucleus is replaced by hydroxyl show properties so different from those of the alcohols of the methane and ethylene series that they are given a distinctive name and are called *phenols*. The simplest compound of the class is *phenol*, C_6H_5OH, or, as it is commercially known, *carbolic acid*. It is one of the constituents of coal-tar, and is obtained partly by fractional distillation, partly by solution in sodium hydroxide, and reprecipitation by sulphuric acid.

When pure, phenol is a colorless solid which melts at 43°, and boils at 183°. It dissolves in 20 parts of water at 17°. It also dissolves a small amount of water, the solution being liquid; hence, if shaken with less than 20 parts of water at 17°, the mixture will separate, on standing, into an upper layer containing about five per cent, and a lower layer containing about seventy-five per cent of phenol.

One of the most marked differences between phenol and the alcohols of the marsh-gas series is in their conduct toward alkalies. While alcoholates, such as sodium ethylate, C_2H_5ONa, can be easily obtained by dissolving metallic sodium or potassium in the anhydrous alcohols, these compounds are instantly decomposed by water with the formation of the hydroxide of the metal and the regeneration of the alcohol. Sodium phenolate, C_6H_5ONa, on the contrary, can be prepared bv dissolving phenol in a solution of sodium hydroxide and evaporating to dryness. Phenol is precipitated from its alkaline solution, however, even by carbonic acid. If other hydrogen atoms of phenol are replaced by negative groups, the resulting substitution products are more strongly acid. Thus trinitro-phenol, or picric acid, $C_6H_2(NO_2)_3OH$, is a sufficiently strong acid to decompose carbonates.

In accordance with the generally accepted theory of solutions, these facts mean that the alcohols of the marsh-gas series dissociate in the pure state, or in aqueous solution, with the formation of fewer hydrogen ions than does water itself, and that phenol undergoes less, while picric acid undergoes more dissociation than carbonic acid. These facts can be given an accurate quantitative expression by means of the conductivity constants (see p. 49).

Picric acid,*	$K=$ ——	Hydrogen sulphide,	$K=0.0000057$
Acetic acid,	$K=0.0018$	Hydrocyanic acid,	$K=0.0000013$
Carbonic acid,	$K=0.0000304$	Phenol	$K=0.00000013$

Water, $K=0.0000000000000062$

In a decinormal solution (i.e., v = 10.) the percentage dissociation is:

Hydrochloric acid . .	91.4	Hydrogen sulphide . . .	0.075
Acetic acid	1.3	Hydrocyanic acid	0.011
Carbonic acid	0.174	Phenol	0.0037

The conductivity of ethyl alcohol is 2×10^{-6}. (*Zeit. phys. Chem.* **57**, 196.) That of water is 3.8×10^{-8}. Wied. Ann. **53**, 209 (1894). Since sodium ethylate, C_2H_5ONa, is decomposed by water even in the presence of a large excess of alcohol, it seems probable that the ionization of ethyl alcohol gives hydroxide ions, chiefly, with very few hydrogen ions. This would explain the difference in conduct of ethyl alcohol and phenol toward phosphorus pentachloride. (See below.)

If we look for the reason for the acid character of phenol, two explanations suggest themselves. One is that with the loss of hydrogen the "positive" or basic character of the group C_2H_5 of ethyl alcohol or C_6H_{11} of cyclohexanol ($C_6H_{11}OH$) passes into a comparatively "negative" or acid character for the group C_6H_5. This view is supported by the conduct of picric acid, where the replacement of hydrogen by negative groups greatly increases the acid character. The other explanation is that, if we assume Kekulè's formula for benzene as correct, the acid character of the hydroxyl is due to the double union of the carbon atom bearing it with another carbon atom of the ring. In support of this view it may be said that no carbon compound containing a hydroxyl group with acid properties is known in which the carbon

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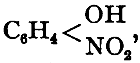
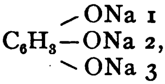
* The conductivity of picric acid is of the same order as that of the strong mineral acids, and a constant cannot be given.

atom combined with the hydroxyl is not doubly united with some other atom. It is very likely that both of the factors mentioned are effective in the case of phenol.

Chemical Character of Phenols. — Just as the introduction of hydroxyl into hydrocarbons of the marsh-gas series produces compounds which are easily oxidized and readily acted upon by other reagents, so phenol gives substitution products more easily, and is in other respects a much less stable compound, than benzene. Strong nitric acid is required to prepare nitrobenzene, $C_6H_5NO_2$, from benzene, while dilute nitric acid will convert phenol into a mixture of ortho- and para-nitrophenol  $C_6H_4<\begin{matrix}OH\\NO_2\end{matrix}$, and trinitrophenol, $C_6H_2(NO_2)_3OH$ is easily prepared.

In alkaline solutions phenols are especially unstable, and easily oxidized. Sodium pyrogallate,  $C_6H_3\begin{matrix}\diagup ONa\ 1\\-ONa\ 2\\\diagdown ONa\ 3\end{matrix}$, absorbs oxygen so rapidly that its solution is used for quantitative determinations in gaseous mixtures.

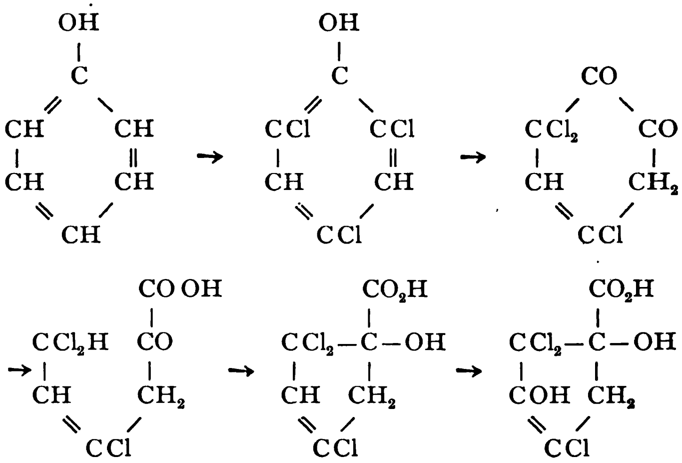
By distillation with zinc dust, phenol is converted into benzene.

By means of phosphorus pentachloride or pentabromide, the hydroxyl of phenol can be replaced by chlorine or bromine.

$$C_6H_5OH + PCl_5 = \underset{\text{Monochlorbenzene.}}{C_6H_5Cl} + POCl_3 + HCl.$$

The reaction takes place with some difficulty, and the yield is poor owing to the formation of triphenyl phosphate, $PO(OC_6H_5)_3$.

By the action of chlorine on a solution of phenol in sodium hydroxide it is converted into trichlorcyclopentenediol carboxylic acid, $C_6H_5Cl_3O_4$, probably through the following stages:

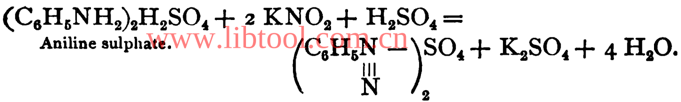


These transformations are of especial interest because a ring of six carbon atoms is changed into one containing five carbon atoms. Similar transformations, which occur both ways with rings containing five, six and seven carbon atoms, have been observed in a number of other cases, and a study of such transformations seems destined to be of increasing importance.

Phenol may be prepared by fusing potassium benzene-sulphonate with caustic potash, or by treating aniline sulphate with nitrous acid (or sodium nitrite) and boiling the resulting benzene diazonium sulphate with water.

$$C_6H_5SO_2OK + KOH = C_6H_5OH + K_2SO_3.$$

Potassium benzene sulphonate.



$$(C_6H_5NH_2)_2H_2SO_4 + 2\,KNO_2 + H_2SO_4 = \left(\begin{array}{c}C_6H_5N-\\ |||\\ N\end{array}\right)_2SO_4 + K_2SO_4 + 4\,H_2O.$$

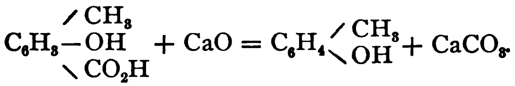
Aniline sulphate.

Benzene diazonium sulphate.

$$(C_6H_5N_2)_2SO_4 + 2\,H_2O = 2\,C_6H_5OH + H_2SO_4 + N_2.$$

Both methods are general, and are especially useful in preparing homologues of phenol, and also in preparing hydroxyl derivatives of naphthalene, anthracene, etc. Phenol is a valuable disinfectant, if applied in not too dilute a solution. Its vapor is worthless for this purpose, however.

Cresol, or Hydroxytoluene, $C_6H_4\begin{array}{l}\diagup CH_3\\ \diagdown OH\end{array}$, exists, in accordance with the theory, in three forms. These are found in coal-tar and in wood-tar. *Creosote,* obtained from wood-tar, contains both phenol and a mixture of the cresols. It is very difficult to prepare the individual cresols from tar, and they are prepared, practically, from toluene-sulphonic acids, $C_6H_4\begin{array}{l}\diagup CH_3\\ \diagdown SO_2OH\end{array}$, or the toluidines (aminotoluenes), $C_6H_4\begin{array}{l}\diagup CH_3\\ \diagdown NH_2\end{array}$, by methods exactly similar to those given under phenol. If a pure ortho, meta, or para compound is used, pure o-, m- or p-cresol can be obtained. Cresols and other phenols may be obtained by distilling hydroxy acids with lime.

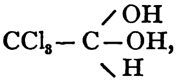


$$C_6H_3\begin{array}{l}\diagup CH_3\\ -OH\\ \diagdown CO_2H\end{array} + CaO = C_6H_4\begin{array}{l}\diagup CH_3\\ \diagdown OH\end{array} + CaCO_3.$$

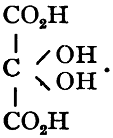
Hydroxy-toluic acid.

This method of preparation is often important as a means of determining the structure of hydroxy acids, or of other compounds (as amino acids, sulphonic acids, etc.) which can be readily converted into hydroxy acids.

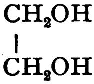
Only in a few unusual cases, and apparently always when the group containing the two hydroxyl groups is combined with a strongly negative group or groups, do exceptions to this general rule occur. Thus chloral hydrate has probably the structure,

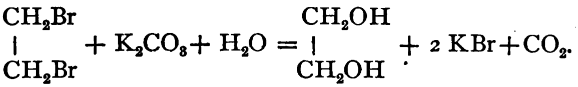


and mesoxalic acid the formula,



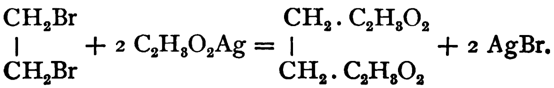
In accordance with what has been said, the first stable alcohol having two hydroxyl groups contains also two carbon atoms; the first one with three hydroxyl groups contains three carbon atoms, and so on for other alcohols containing several hydroxyl groups.

Glycol,  $\begin{matrix} CH_2OH \\ | \\ CH_2OH \end{matrix}$ **(ethandiol),** may be prepared by boiling ethylene bromide with a solution of potassium carbonate.



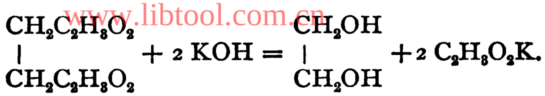
$$\begin{matrix} CH_2Br \\ | \\ CH_2Br \end{matrix} + K_2CO_3 + H_2O = \begin{matrix} CH_2OH \\ | \\ CH_2OH \end{matrix} + 2\,KBr + CO_2.$$

The diacetic ester of glycol can be prepared by heating ethylene bromide with silver acetate.



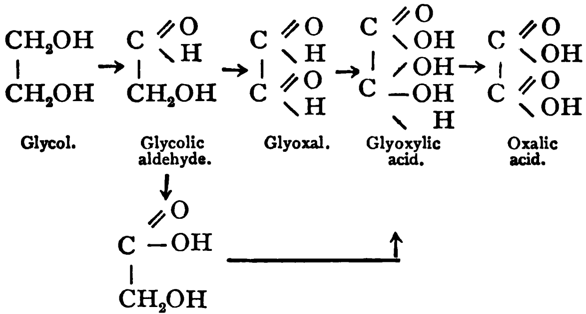
$$\begin{matrix} CH_2Br \\ | \\ CH_2Br \end{matrix} + 2\,C_2H_3O_2Ag = \begin{matrix} CH_2 . C_2H_3O_2 \\ | \\ CH_2 . C_2H_3O_2 \end{matrix} + 2\,AgBr.$$

The ester may be saponified with caustic potash.



$$\begin{array}{l}CH_2C_2H_3O_2\\ |\\ CH_2C_2H_3O_2\end{array} + 2\,KOH = \begin{array}{l}CH_2OH\\ |\\ CH_2OH\end{array} + 2\,C_2H_3O_2K.$$

Glycol is a colorless liquid with a sweet taste. It boils at 197°, and solidifies in a freezing mixture. Its chemical conduct corresponds to its structure as a primary alcohol. From this structure we should expect the following series of oxidation products:

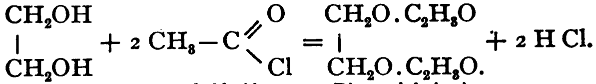


All of these substances are known, but some of them have not been prepared by direct oxidation of glycol, and all of them can be more easily prepared by other methods.

The official names for these compounds are: *ethanediol, ethanolal, ethanedial, ethanolic acid, ethanediolic acid, ethanediacid.*

Glycol forms alcoholates in which one or both of the hydrogen atoms of the hydroxyl groups are replaced by alkali metals. The sodium glycolate, $C_2H_4O_2Na_2$, crystallizes with $10H_2O$, from which it seems that glycol is more acid in character than ethyl alcohol (see p. 143).

With acids glycol forms esters in which one or both of the alcoholic hydrogen atoms may be replaced by the acyl group. These may be prepared by the use of the silver or potassium salts of the acid (see above), or by the action of the acid chloride on glycol.

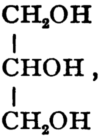


Acetyl chloride

Di-acetyl derivative of glycol.

Propylene glycol, or 1,2 **Propanediol**, $CH_2OH, CHOH, CH_3$, and **Trimethylene glycol,** or 1.3 **Propanediol,** CH_2OH, CH_2, CH_2OH are both known. The latter has been found in impure glycerol, and appears to have been formed by the reduction of glycerol under the influence of bacteria. (*J. Am. Ch. Soc.* 17, 890.)

Glycerol,* or **Propanetriol,**



$$\begin{array}{l} CH_2OH \\ | \\ CHOH, \\ | \\ CH_2OH \end{array}$$

occurs combined with acids in the natural fats, the most common compounds being *stearin*, $C_3H_5(C_{18}H_{35}O_2)_3$, found in tallow and lard; *palmitin*, $C_3H_5(C_{16}H_{31}O_2)_3$, found in palm-oil and lard; and *oleïn*, $C_3H_5(C_{18}H_{33}O_2)_3$, found in olive-oil and lard. When the fats are boiled with aqueous or alcoholic solutions of potassium or sodium hydroxide, they are *saponified* or decomposed with the formation of glycerol and the metallic salt of the organic acid. The latter is a *soap*.

$$\underset{\text{Stearin.}}{C_3H_5(C_{18}H_{35}O_2)_3} + 3\,NaOH = \underset{\text{Glycerol.}}{C_3H_5(OH)_3} + \underset{\text{Sodium stearate.}}{3\,C_{18}H_{35}O_2Na.}$$

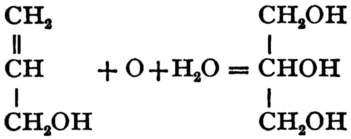
---

* The scientific name is used, though it will be long before "glycerine" will be displaced in common usage.

Commercially the fat is saponified by heating it with water and four per cent of its weight of lime in an autoclave. The acids obtained are used as commercial "stearine" in the manufacture of candles, and for other purposes, while the aqueous solution containing the glycerol is distilled with superheated steam.

Glycerol has been prepared synthetically by heating 1.2.3 tribrompropane with silver acetate and saponifying the triacetin, $C_3H_5(C_2H_3O_2)_3$, which is formed, with barium hydroxide.

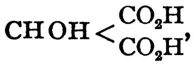
It has also been prepared by oxidizing allyl alcohol with potassium permanganate.



$$\begin{array}{l} CH_2 \\ \| \\ CH \\ | \\ CH_2OH \end{array} + O + H_2O = \begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{array}$$

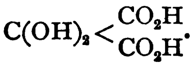
Pure glycerol is a very viscous sweet syrup, having a specific gravity at 15° of 1.265. It solidifies slowly at a low temperature, and the crystals melt at 17°. It boils with slight decomposition at 290°. Under a pressure of 50 mm. it boils at 210°; under 12.5 mm., at 180°.

The chemical conduct of glycerol is in strict accordance with its structure. The most interesting of its oxidation products are *glyceric acid* (*propanediolic acid*), $CH_2OH\text{-}CHOH\text{-}CO_2H$, *tartronic acid* (*propanoldiacid*),



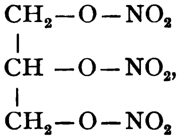
$$CHOH<\begin{array}{l} CO_2H \\ CO_2H \end{array},$$

and *mesoxalic acid* (*propanediol diacid*),

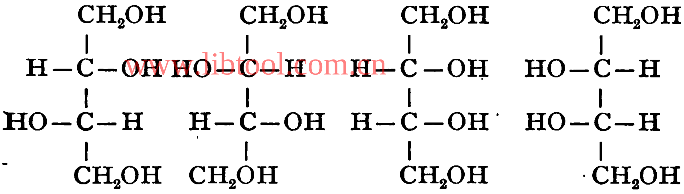


$$C(OH)_2<\begin{array}{l} CO_2H \\ CO_2H \end{array}.$$

The last cannot be further oxidized without loss of carbon.

Glyceryl Trinitrate, 
$$\begin{array}{l} CH_2-O-NO_2 \\ \mid \\ CH\ -O-NO_2, \\ \mid \\ CH_2-O-NO_2 \end{array}$$
is prepared by running glycerol slowly into a mixture of strong sulphuric and nitric acids, the temperature being carefully controlled. It is known commercially as *nitroglycerine.* It solidifies at −20°. At ordinary temperatures it is a light yellow liquid with a specific gravity of 1.6009 at 15°. In small quantities it can be burned quietly. It explodes on concussion, with a detonating cap, or when heated to 250°. Nitric oxide, carbon dioxide, water and nitrogen are formed by the detonation. The poisonous character of the nitric oxide sometimes causes trouble when nitroglycerine or dynamite is used for blasting in confined spaces. *Dynamite* is prepared by mixing nitroglycerine with infusorial earth (kieselguhr), sawdust, or the pith of corn-stalks, the most powerful forms containing 75 per cent of nitroglycerine. A mixture containing 93 per cent. of nitroglycerine and 7 per cent of nitrocellulose (gun-cotton) forms a semi-solid, gelatinous mass known as *explosive gelatine.* Nitroglycerine is also used in medicine as a heart stimulant. It is a powerful poison.

Erythrol, $CH_2OH,CHOH,CHOH,CH_2OH$.— Glycol and glycerol cannot exist in optically active forms, since neither contains an asymmetric carbon atom. Erythrol, however, contains two such atoms. At first thought this should give, by the various possible combinations, four active forms and two racemic mixtures. The active forms on this supposition may be written as follows:



$$\begin{array}{c} CH_2OH \\ | \\ H-C-OH \\ | \\ HO-C-H \\ | \\ CH_2OH \end{array} \quad \begin{array}{c} CH_2OH \\ | \\ HO-C-H \\ | \\ H-C-OH \\ | \\ CH_2OH \end{array} \quad \begin{array}{c} CH_2OH \\ | \\ H-C-OH \\ | \\ H-C-OH \\ | \\ CH_2OH \end{array} \quad \begin{array}{c} CH_2OH \\ | \\ HO-C-H \\ | \\ HO-C-H \\ | \\ CH_2OH \end{array}$$

d-Erythrol. *l*-Erythrol. *i*-Erythrol (m. p. 126°).

(*d* + *l*) Erythrol (m. p. 72°).

A little examination shows, however, that the third and fourth forms, above, are inactive by an internal compensation, since the two halves of the molecule are identical and turned in opposite directions. A study of the models also shows that these two forms are identical, and that the difference in writing the formulae does not correspond to any real difference in structure. The first and second formulae, on the other hand, represent right-handed and left-handed forms which may actually exist. From the above there should be two active forms of erythrol, an inactive, racemic form resulting from the combination of the first two, and an inactive form which is inactive by internal compensation.

No active form of erythrol has been prepared, but two forms are known, one melting at 72°, the other at 126°. If 1,3 butadiene, $CH_2 = CH - CH = CH_2$, is treated with bromine, the bromine atoms appear to add themselves to the end carbon atoms, while a double union is formed between the two central atoms. The compound at first formed is unstable, but on warming to 100° two stable forms result. If we assume that so long as carbon atoms are united singly a free rotation at the point of union is possible, but that when doubly united such free rotation becomes impossible, the following formulae may be assigned to the two dibromides:

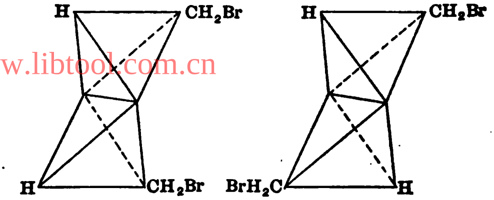


Fig. 26.

Isomerism of this kind is called *geometrical isomerism*, or *stereoisomerism*, because the explanation given involves a discussion of the actual arrangement of the atoms and groups in space. The fundamental conception in this explanation is closely related to the doctrine of the asymmetric carbon atom, which is that the four atoms or groups, combined with any given carbon atom, naturally arrange themselves in approximate, or, if the groups or atoms are identical, in absolute symmetry about the center of that atom. In figures the carbon atom is sometimes represented in the form of a tetrahedron, as a matter of convenience, but it must not be supposed that any satisfactory evidence as to the real form of the carbon atom has thus far been obtained.

If the two bromine compounds are oxidized by potassium permanganate, two different dibrombutanediols, $C_4H_6Br_2(OH)_2$ are formed. These will have the structures:

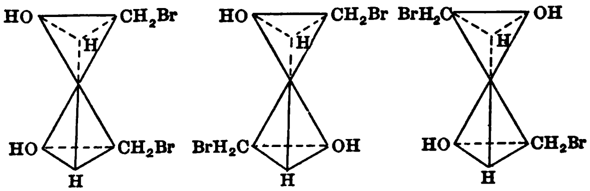
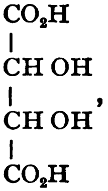


Fig. 27.

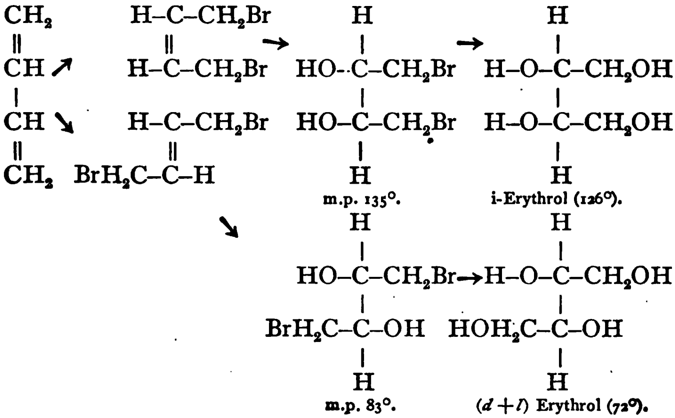
On studying these formulae it will be seen that the first compound is inactive by internal compensation, while the second and third are active, the one being right-handed, the other left-handed. By means of caustic potash the two dibrombutanediols are converted into the two erythrols which have been referred to. By oxidation the erythrol which melts at 126° is converted into mesotartaric acid,

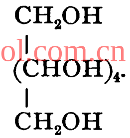


$$\begin{array}{l} CO_2H \\ | \\ CH\,OH \\ | \\ CH\,OH \\ | \\ CO_2H \end{array},$$

the tartaric acid which is inactive by internal compensation, since it cannot be separated into active forms. From this it follows that this erythrol is also inherently inactive; and it is further assumed that the erythrol melting at 72° is a racemic mixture of the right and left forms of an active compound.

The relations which have been sketched can be represented by means of an adaptation of ordinary formulae as follows:



Hexanehexols,  $\begin{matrix}CH_2OH\\ |\\ (CHOH)_4\\ |\\ CH_2OH\end{matrix}$. As these compounds contain four asymmetric carbon atoms, a very considerable number of isomers is possible, and several of them are known. The most important are *mannite*, which is found in manna, and is also formed by the reduction of glucose, fructose, or mannose; *dulcite*, formed by the reduction of milk sugar and galactose; and *sorbite*, formed by the reduction of gulose, glucose, or fructose. Since both mannite and dulcite give 2-iodohexane by reduction with hydriodic acid, and since glucose gives both mannite and sorbite by reduction, all three of these compounds must contain a normal chain of carbon atoms. The isomerism is probably due to differences in configuration, that is, to the arrangement of the groups in space. This configuration has been determined with a good degree of certainty by methods somewhat similar to those which have been given for the erythrols.

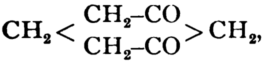
Pyrocatechol (o-dihydroxybenzene or 1.2 **phendiol),** $C_6H_4(OH)_2$, is formed by fusing o-iodophenol or o-phenolsulphonic acid with caustic potash. Pyrocatechol melts at 104°, and boils at 240°–245°. It is easily soluble in water.

Resorcinol (1.3 **phendiol**) is formed by melting m-iodophenol or m-benzene-disulphonic acid with caustic potash. It is also formed by the fusion of o-bromphenol with caustic potash. This latter fact, and others like it, led at one time to serious confusion in the relation between the derivatives of benzene; and for a number of years many compounds which are really ortho were called meta, and compounds which are really meta were called ortho. In using the earlier literature this must be remembered.

Rearrangements of this kind appear to be especially liable to occur in fusions with caustic potash, and that means is avoided, if possible, in determining the constitution of benzene derivatives.

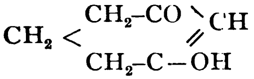
Resorcinol condenses easily with phthalic anhydride to form fluoresceïn, and it is manufactured for use in making this and other dyestuffs.

When resorcinol in aqueous solution is boiled with sodium amalgam, while carbon dioxide is passed through the mixture, it takes up two atoms of hydrogen, but the resulting dihydroresorcinol does not conduct itself as a dihydroxy compound, but reacts sometimes as 1.3 *cyclohexanedione*,



$$CH_2<\begin{matrix}CH_2-CO\\CH_2-CO\end{matrix}>CH_2,$$

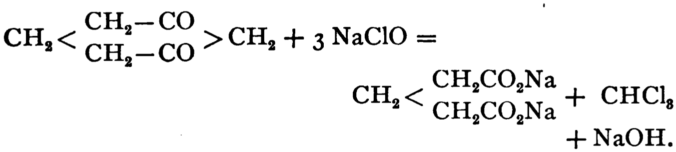
and sometimes as 1.3 *cyclohexenolone*,



$$CH_2<\begin{matrix}CH_2-CO\\CH_2-C-OH\end{matrix}\begin{matrix}\searrow\\ /\!\!/\end{matrix}CH$$

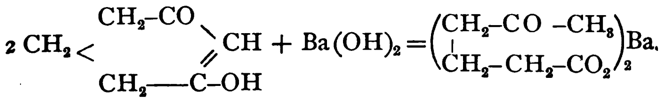
This is a sufficiently strong acid to decompose carbonates, although it contains no carboxyl group (p. 220).

When dihydroresorcinol is treated with sodium hypochlorite it gives sodium glutarate and chloroform.



$$CH_2<\begin{matrix}CH_2-CO\\CH_2-CO\end{matrix}>CH_2+3\,NaClO=CH_2<\begin{matrix}CH_2CO_2Na\\CH_2CO_2Na\end{matrix}+CHCl_3+NaOH.$$

When boiled with a solution of barium hydroxide it undergoes hydrolysis, giving the barium salt of γ-acetylbutyric acid,

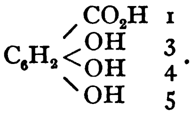


$$2\,CH_2<\begin{matrix}CH_2-CO\\CH_2-C-OH\end{matrix}\begin{matrix}\searrow\\ /\!\!/\end{matrix}CH+Ba(OH)_2=\begin{pmatrix}CH_2-CO-CH_3\\ |\qquad\qquad\\ CH_2-CH_2-CO_2\end{pmatrix}_2Ba.$$

These reactions furnish additional proof of the relation between the carbon atoms of cyclohexane and of benzene (p. 100). Resorcinol melts at 119°, and boils at 276°. It dissolves in two-thirds of its weight of water at 13°.

Hydroquinone (1-4 **phendiol**) is most easily prepared by the reduction of quinone, $C_6H_4O_2$. It is readily converted into quinone by oxidizing agents. For this reason it is a mild reducing agent, and is used as such for a "developer" in photography. Hydroquinone melts at 169°. It dissolves in 16 parts of water at 15°.

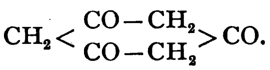
Pyrogallol (1.2.3 **phentriol**) is prepared by the dry distillation of *gallic acid*,



$$C_6H_2 \begin{array}{l} \diagup CO_2H \quad 1 \\ \diagup OH \quad\; 3 \\ \diagdown OH \quad\; 4 \\ \diagdown OH \quad\; 5 \end{array} .$$

A solution of pyrogallol in sodium or potassium hydroxide absorbs oxygen so rapidly that it is used for that purpose in gas analysis. Carbonates and acetates are formed, together with a small amount of carbon monoxide, and dark-colored decomposition products. Pyrogallol melts at 132° and boils, with some decomposition, at 294°.

Phloroglucinol (1.3.5 **phentriol**) is interesting because, while its general conduct is that of a phenol, it reacts in some cases as though it were the 1.3.5 *hexanetrione*,



$$CH_2 < \begin{array}{l} CO - CH_2 \\ CO - CH_2 \end{array} > CO.$$

In the foregoing discussion of alcohols the student will understand, of course, that only a very few, comparatively, have been considered. Many others might be given, some of them of at least equal importance with those which are mentioned.

The following is a summary of the general methods of preparing alcohols:

1. By fermentation, especially ethyl, propyl, isobutyl and isoamyl alcohols.

2. By heating an alkyl halide with water, with lead oxide or silver oxide and water, or with potassium or silver acetate. In the last case an acetic ester of the alcohol results, which must be saponified.

$$CH_3I + H_2O = CH_3OH + HI.$$

$$CH_3I + C_2H_3O_2Ag = CH_3C_2H_3O_2 + AgI.$$

Methyl acetate.

3. By treating an unsaturated hydrocarbon with concentrated sulphuric acid, diluting with water and distilling, which causes the saponification of the acid ester of sulphuric acid at first formed.

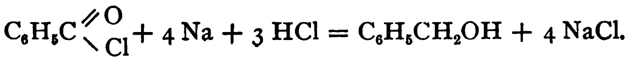
$$C_2H_4 + H_2SO_4 = C_2H_5HSO_4.$$

Ethyl sulphuric acid.

$$C_2H_5HSO_4 + H_2O = C_2H_5OH + H_2SO_4.$$

If the hydrocarbon contains more than two carbon atoms, a secondary or tertiary alcohol will be formed, and thus a means is furnished of passing from a primary to a secondary or tertiary alcohol. (How could isopropyl alcohol be prepared in this way from normal propyl alcohol?)

4. By the reduction of an aldehyde, ketone, or acid chloride.



$$C_6H_5C\begin{smallmatrix}{/\!\!/}O\\ \diagdown Cl\end{smallmatrix} + 4\,Na + 3\,HCl = C_6H_5CH_2OH + 4\,NaCl.$$

Benzoyl chloride. Benzyl alcohol.

5. By treatment of an amine with nitrous acid. In the case of "aromatic" amines a diazo compound is formed as an intermediate product (p. 147).

$$C_2H_5NH_2 + HNO_2 = C_2H_5OH + H_2O + N_2.$$

Ethyl amine.

6. Fusion of an aromatic sulphonic acid or halogen compound with caustic potash, giving a phenol.

$$C_6H_5SO_3K + KOH = C_6H_5OH + K_2SO_3.$$

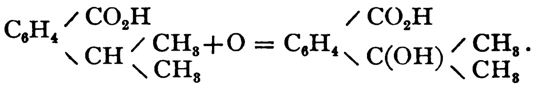
Potassium benzene sulphonate. Phenol.

7. Oxidation of an unsaturated compound with potassium permanganate, giving a glycol or dihydroxy compound.

$$CH_2{=}CH_2 + O + H_2O = CH_2(OH)-CH_2(OH).$$

Ethylene. Glycol.

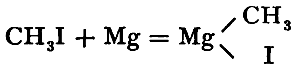
8. Some acids containing a tertiary hydrogen atom may be oxidized to a hydroxy acid by potassium permanganate.



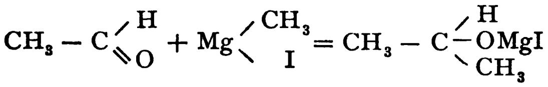
$$C_6H_4\left\langle\begin{array}{l}CO_2H\\ CH\left\langle\begin{array}{l}CH_3\\ CH_3\end{array}\right.\end{array}\right. + O = C_6H_4\left\langle\begin{array}{l}CO_2H\\ C(OH)\left\langle\begin{array}{l}CH_3\\ CH_3\end{array}\right.\end{array}\right. .$$

p.-Isopropyl benzoic acid. p.-Hydroxyisopropyl benzoic acid.

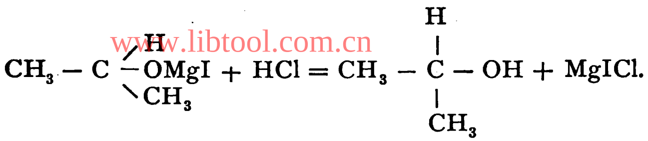
9. Secondary or tertiary alcohols may be prepared by adding an aldehyde or ketone to an organo-magnesium halide and decomposing the resulting compound with dilute acid. (Grignard's reaction.) The organo-magnesium halide is obtained by adding an alkyl halide to magnesium powder suspended in anhydrous ether.



$$CH_3I + Mg = Mg\left\langle\begin{array}{l}CH_3\\ I\end{array}\right.$$



$$CH_3 - C\left\langle\begin{array}{l}H\\ O\end{array}\right. + Mg\left\langle\begin{array}{l}CH_3\\ I\end{array}\right. = CH_3 - C\left\langle\begin{array}{l}H\\ OMgI\\ CH_3\end{array}\right.$$



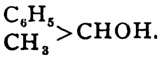
$$CH_3-C\begin{matrix}\diagup H\\-OMgI\\\diagdown CH_3\end{matrix}+HCl=CH_3-\overset{\overset{\displaystyle H}{|}}{\underset{\underset{\displaystyle CH_3}{|}}{C}}-OH+MgICl.$$

(The student is advised to write similar reactions starting with acetone, $\begin{matrix}CH_3\\CH_3\end{matrix}>CO$.) See *Am. Chem. J.* 33, 304.

Most of the methods given can be used for the preparation of hydroxy acids and of hydroxyl derivatives of other compounds, as well as for the preparation of alcohols.

Laboratory Exercises.

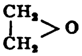
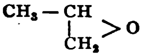
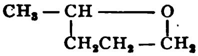
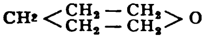
1. Preparation of ethyl alcohol by fermentation.
2. Determination of the per cent of "fusel oil" in a sample of whisky.
3. Preparation of allyl alcohol.
4. Preparation of *p*-cresol.
5. Preparation of benzyl alcohol.
6. Preparation of α or β naphthol.
7. Preparation of glycol.
8. Distillation of glycerol under diminished pressure.
9. Preparation of hydroquinone.
10. Preparation of phenyl-methyl carbinol,



$$\begin{matrix}C_6H_5\\CH_3\end{matrix}>CHOH.$$

CHAPTER XI.

ETHERS.

		Boiling Point.	Specific Gravity.
Methyl ether	$(CH_3)_2O$	— 23.65°	
Methyl ethyl ether	$\begin{matrix}CH_3\\C_2H_5\end{matrix}>O$	10.8°	0.7252 (0°)
Ethyl ether	$(C_2H_5)_2O$	34.6°	0.718 (15.6°)
Normal propyl ether	$(C_3H_7)_2O$	90.7°	0.7443 (21°)
Isopropyl ether	$\left(\begin{matrix}CH_3\\CH_3\end{matrix}>CH\right)_2O$	69°	0.7247 (21°)
Methyl propyl ether	$\begin{matrix}C_3H_7\\CH_3\end{matrix}>O$	38.9°	0.7471 (0°)
Isoamyl ether	$\left(\begin{matrix}CH_3\\CH_3\end{matrix}>CH-CH_2CH_2\right)_2O$	173°	0.7807 (15°)
Vinyl ether	$(CH_2=CH)_2O$	39°	—
Allyl ether	$(CH_2=CH-CH_2)_2O$	94.3°	0.8046 (18°)
Methyl propargyl ether	$\begin{matrix}CH\equiv C-CH_2\\CH_3\end{matrix}>O$	62°	0.83
Phenyl ether	$(C_6H_5)_2O$	253°	—
Methyl phenyl ether (Anisol)	$\begin{matrix}CH_3\\C_6H_5\end{matrix}>O$	155.°	1.0110 (0°)
Ethyl phenyl ether (Phenetol)	$\begin{matrix}C_2H_5\\C_6H_5\end{matrix}>O$	172°	0.9822 (0°)
αα Naphthyl ether	$(C_{10}H_7)_2O$	Above 360°	—
Ethylene oxide		13.5°	0.8966 (0°)
Propylene oxide		35°	0.859 (0°)
γ-Pentylene oxide		78°	0.8748 (0°)
Pentamethylene oxide	 $CH_2<\begin{matrix}CH_2-CH_2\\CH_2-CH_2\end{matrix}>O$	82°	0.880 (0°)

Ethyl ether $(C_2H_5)_2O$, the best known, and by far the most important, of the ethers, is prepared by mixing alcohol and concentrated sulphuric acid in such proportion that the mixture will distill at about 140°. A mixture of water, ether, and alcohol distills over, and, if alcohol is run in at such a rate that the boiling point remains nearly constant, a given portion of sulphuric acid will convert a relatively large amount of alcohol into ether. Theoretically, an infinitely great amount should be so converted, but the process comes to an end through the formation of sulphur dioxide and other secondary products.

Superficially considered, the reaction seems to consist merely in the removal of water from the alcohol:

$$2\,C_2H_5OH - H_2O = \begin{matrix}C_2H_5\\C_2H_5\end{matrix}\!>O.$$

Historical. — In the earlier study of carbon compounds the apparently simple relation between alcohol and ether, and the fact that ether has a much lower boiling point (34.6°) than alcohol (78.3°), led chemists to suppose that ether is a simpler body than alcohol, and to write the formulae C_4H_5O and $C_4H_5O.HO$.* Such formulae were, of course, possible only at a time when the determination of molecular weights by means of the vapor density was not considered reliable.

In 1842 Gerhardt pointed out that the formula of ether as given above should be doubled in comparison with that of alcohol, basing his belief partly on the vapor densities of the two substances.

It was not, however, till 1851, when Williamson showed that ether is formed by heating sodium ethylate with ethyl

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* In these old formulae which were in common use by many chemists from 1830 to 1850, and by some for a much longer period, C = 6, O = 8, and water was written HO.

iodide, that the true relation between alcohol and ether was generally recognized. Williamson's reaction still remains the best proof of the structure of ether, and, in its generalized form, the best method for the preparation of many ethers.

$$R - O - Na + R'I = R - O - R' + NaI.$$

The two radicals which are combined by this reaction may be identical or different. In the latter case mixed ethers, as, for instance, methyl ethyl ether, $\begin{matrix}CH_3\\C_2H_5\end{matrix}\!>O$, methyl phenyl ether, or *anisol*, $\begin{matrix}CH_3\\C_6H_5\end{matrix}\!>O$, ethyl phenyl ether, or *phenetol*, $\begin{matrix}C_2H_5\\C_6H_5\end{matrix}\!>O$, and the like, are formed. Williamson's discovery was not only of value in establishing the structure of ether, but was also of far-reaching importance in its influence upon the views of chemists as to the atomic weights of the elements, the formula of water, and the structure of both organic and inorganic compounds. The discussions with reference to ethyl ether are, therefore, of fundamental importance in the history of chemistry.

In considering the etherification of alcohol by means of sulphuric acid, it becomes evident that the reaction does not consist merely in the removal of water from two molecules of the alcohol by the acid, since both water and ether distill over together. When the sulphuric acid and alcohol are mixed, they combine, in part, to form the acid ester of sulphuric acid:

$$C_2H_5OH + H_2SO_4 = \underset{\text{Ethyl sulphuric acid.}}{C_2H_5HSO_4} + H_2O.$$

This acid ester then reacts, in part, with more alcohol:

$$C_2H_5HSO_4 + C_2H_5OH = (C_2H_5)_2O + H_2SO_4.$$

The water and the ether formed by the two reactions distill over, while the regenerated sulphuric acid remains behind.

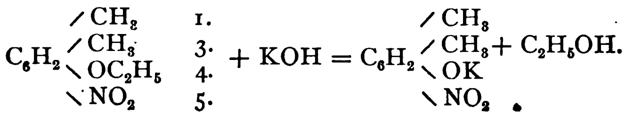
Physical Properties. — Pure ethyl ether is a very mobile liquid which boils at 34.6°, and has a specific gravity of 0.718 at 15.6°. It dissolves in 11.1 volumes of water at 25°, while it will, in turn, dissolve one-fiftieth of its volume of water. Because of its low boiling point, its vapors form explosive mixtures with air, and care is required in its use. Commercial ether usually contains alcohol, which can be removed by repeated washing with small amounts of water, and water, which can be mostly removed by calcium chloride and the last portions by means of sodium, best in the form of wire. On account of its volatility, ether should be kept in tightly-corked, strong bottles, and these are best filled full.

Chemical Conduct. — In their chemical conduct the ethers are generally very stable bodies, and remain unchanged when boiled with solutions of alkaline hydroxides or dilute acids. Concentrated sulphuric acid gives with ethyl ether, however, ethyl sulphuric acid, and hydriodic acid gives alcohol and ethyl iodide:

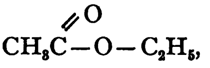
$$(C_2H_5)_2O + 2H_2SO_4 = 2C_2H_5HSO_4 + H_2O.$$

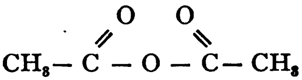
$$(C_2H_5)_2O + HI = C_2H_5OH + C_2H_5I.$$

In some cases of mixed ethers containing one strongly negative group the ethers may be decomposed by boiling with caustic potash. Thus the ethyl nitrodimethylphenyl ether may be decomposed in this manner:



$$C_6H_2\begin{array}{l} /CH_3 \\ /CH_3 \\ \backslash OC_2H_5 \\ \backslash NO_2 \end{array} \begin{array}{l} 1. \\ 3. \\ 4. \\ 5. \end{array} + KOH = C_6H_2\begin{array}{l} /CH_3 \\ /CH_3 \\ \backslash OK \\ \backslash NO_2 \end{array} + C_2H_5OH.$$

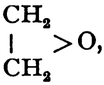
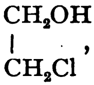
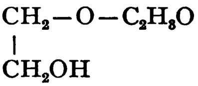
One of the alcohols or phenols in such cases is decidedly acid in character, and the decomposition resembles the saponification of esters (p. 283). It is worthy of notice that, with an increase in negative properties, the stability toward water and alkalies for groups united with oxygen decreases. Thus ethyl ether cannot be decomposed by water or alkalies, acetic ester,  $CH_3\overset{O}{\overset{\|}{C}}-O-C_2H_5$, is readily decomposed by alkalies and slowly by water, and acetic anhydride,



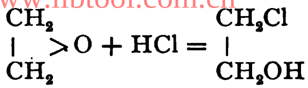
$$CH_3-\overset{O}{\overset{\|}{C}}-O-\overset{O}{\overset{\|}{C}}-CH_3$$

is quite readily decomposed by water. A somewhat similar instability in the union of carbon atoms, occasioned by the presence of negative groups, will find mention later (p. 351).

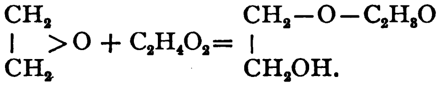
It need scarcely be said that very many ethers are known, but none of the simple ethers require further mention here. No simple ethers of tertiary alcohols are known, but several mixed ethers derived from such alcohols have been prepared.

Ethylene Oxide,  $\begin{matrix}CH_2\\ |\\ CH_2\end{matrix}>O$, may be considered as a cyclic ether. It is prepared by treating *glycol chlorhydrin*, (1-chlorethanol-2),  $\begin{matrix}CH_2OH\\ |\\ CH_2Cl\end{matrix}$, with caustic potash, or by treating *glycol monoacetate*,  $\begin{matrix}CH_2-O-C_2H_3O\\ |\\ CH_2OH\end{matrix}$, with hydrochloric acid gas, and the resulting product with caustic potash. Ethylene oxide boils at 13.5°, and has a specific gravity of 0.8966 at 0°. It mixes with water in all proportions.

Ethylene oxide combines directly with acids forming esters of glycol:



$$\left.\begin{array}{l}CH_2\\ |\\ CH_2\end{array}\right>O + HCl = \begin{array}{l}CH_2Cl\\ |\\ CH_2OH\end{array}$$



$$\left.\begin{array}{l}CH_2\\ |\\ CH_2\end{array}\right>O + C_2H_4O_2 = \begin{array}{l}CH_2-O-C_2H_3O\\ |\\ CH_2OH.\end{array}$$

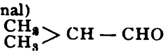
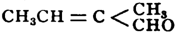
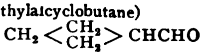
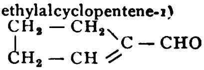
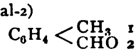
These reactions bring out the very marked difference between ethylene oxide and the ordinary ethers.

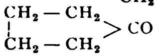
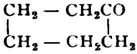
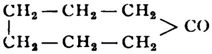
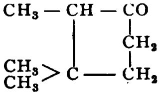
Laboratory Exercises.

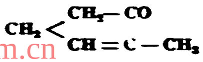
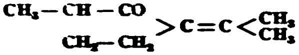
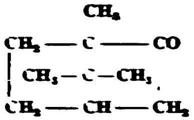
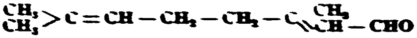
1. Preparation of ethyl ether.
2. Preparation of anisol.

CHAPTER XII.

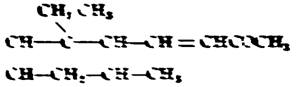
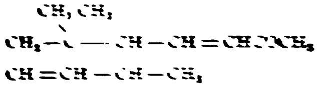
ALDEHYDES AND KETONES.

		BOILING POINT.	SPECIFIC GRAVITY.
Formaldehyde (Methanal)	$HCHO$	— 21°	0.8153 (— 20°)
Acetaldehyde (Ethanal)	CH_3CHO	20.8°	0.8009 (0°)
Propionic aldehyde (Propanal)	CH_3CH_2CHO	48.8°	0.8320 (0°)
Butyric aldehyde (Butanal)	$CH_3CH_2CH_2CHO$	74°	0.911 (0°)
Isobutyric aldehyde (Methyl propanal)	 $\begin{matrix}CH_3\\CH_3\end{matrix}>CH-CHO$	61°	0.8618 (0°)
Valeric aldehyde (Butanal)	$CH_3CH_2CH_2CH_2CHO$	103.4°	0.8185 (11.2°)
Isovaleric aldehyde (2-Methyl butanal-4)	 $\begin{matrix}CH_3\\CH_3\end{matrix}>CHCH_2CHO$	92°	0.8222 (0°)
Caproic aldehyde (Hexanal)	$CH_3(CH_2)_4CHO$	129°	0.8498 (0°)
Oenanthaldehyde (Heptanal)	$CH_3(CH_2)_5CHO$	155°	0.8231 (15°)
Acroleïn (Propenal)	$CH_2=CH-CHO$	52.4°	—
Crotonic aldehyde (2-Butenal)	$CH_3CH=CHCHO$	104°	1.033 (0°) (?)
Tiglic aldehyde (2-Methyl-2-butenal)	 $CH_3CH=C<\begin{matrix}CH_3\\CHO\end{matrix}$	117°	0.871 (15°)
Tetramethylene aldehyde (Methylalcyclobutane)	 $CH_2<\begin{matrix}CH_2\\CH_2\end{matrix}>CHCHO$	116°	—
Δ¹ Cyclopentene aldehyde (Methylalcyclopentene-1)		—	—
Benzaldehyde (Phenmethylal)	C_6H_5CHO	179.5°	1.0636 (0°)
Phenyl acetaldehyde (Phenethylal)	$C_6H_5CH_2CHO$	193°	1.085
o-Toluic aldehyde (Methylphenmethylal-2)	 $C_6H_4<\begin{matrix}CH_3 & 1\\CHO & 2\end{matrix}$	200°	—
Hydrocinnamic aldehyde (Phenpropylal)	$C_6H_5CH_2CH_2CHO$	208°	—

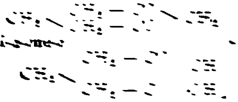
Cuminic aldehyde (4-metho-ethylphenmethylal)	$C_6H_4<\begin{matrix}CH<\begin{matrix}CH_3\\CH_3\end{matrix} & 1\\ CHO & 4\end{matrix}$	237°	0.9832 (0°)
Cinnamic aldehyde (phenpropenylal)	$C_6H_5CH = CHCHO$	129° (20 *mm*)	1.0497 (24°)
α-Naphthaldehyde (naphthenemethylal)	$C_{10}H_7CHO$	291.6°	——
Acetone (propanone)	CH_3COCH_3	56.5°	0.818 (0°)
Methyl ethyl ketone (butanone)	$CH_3COC_2H_5$	80.6°	0.8296 (0°)
Diethyl ketone (3-pentanone)	$\begin{matrix}CH_3CH_2\\CH_3CH_2\end{matrix}>CO$	102°	0.8264 (0°)
Methyl propyl ketone (2-pentanone)	$\begin{matrix}CH_3CH_2CH_2\\CH_3\end{matrix}>CO$	102.7°	0.8335 (0°)
Methyl isopropyl ketone (methyl butanone)	$\begin{matrix}\begin{matrix}CH_3\\CH_3\end{matrix}>CH\\CH_3\end{matrix}>CO$	95°	0.822 (0°)
Pinacolin (dimethyl butanone)	$\begin{matrix}(CH_3)_3\equiv C\\CH_3\end{matrix}>CO$	106°	0.8265 (0°)
Ethylidene acetone (2-pentenone)	$\begin{matrix}CH_3CH=CH\\CH_3\end{matrix}>CO$	122°	0.861 (15°)
2-Methyl-1-butenone-3	$CH_3-CO-C\begin{matrix}/\!\!/ CH_2\\ \diagdown CH_3\end{matrix}$	100°	——
Mesityl oxide (2-methyl-2-pentenone-4)	$\begin{matrix}CH_3\\CH_3\end{matrix}>C=CH-CO-CH_3$	130°	0.8706 (4°)
Acetyl trimethylene (ethanoyl cyclopropane)	$CH_3COCH<\begin{matrix}CH_2\\ \vert\\CH_2\end{matrix}$	115°	——
Adipic ketone (cyclopentanone)		130°	0.9416 (21.5°)
Pimelic ketone (cyclohexanone)		154.5°	0.9473 (20°)
Suberone (cycloheptanone)		178.5°	0.9685 (0°)
2,33 Trimethyl cyclopentanone		168°	0.8956 (20°)
l-Menthone (2-methyl-5-isopropyl cyclohexanone)	$CH_3-CH<\begin{matrix}CO-CH_2\\CH_2-CH_2\end{matrix}>CH-CH<\begin{matrix}CH_3\\CH_3\end{matrix}$	207°	0.896 (20°)

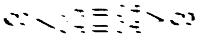
1-Methyl cyclopentene-1-one-3	 $CH_2<\begin{matrix}CH_2-CO\\CH=C-CH_3\end{matrix}$	157°	0.9808 (16°)
Camphorphorone	 $\begin{matrix}CH_3-CH-CO\\CH_2-CH_2\end{matrix}>C=C<\begin{matrix}CH_3\\CH_3\end{matrix}$	205°	0.939 (12°)
Camphor		209.1°	—
Geranial, Citral (2,6-dimethyl-2,6-octadienal-8)  $\begin{matrix}CH_3\\CH_3\end{matrix}>C=CH-CH_2-CH_2-C\overset{CH_3}{\diagdown}CH-CHO$		226°	0.897 (15°)

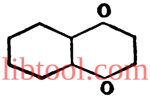
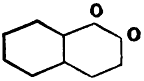
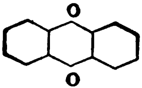
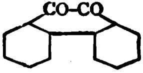
Acetophenone (ethylonephen)	$C_6H_5COCH_3$	202°	1.032 (15°)
Ethyl phenyl ketone (1¹-propylonephen)	$C_6H_5COC_2H_5$	215.5°	1.009 (0°)
Methyl benzyl ketone (1²-propylonephen)	$C_6H_5CH_2COCH_3$	215°	1.010 (3°)

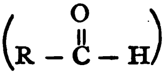
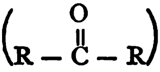
Irone		144° (16 mm)	0.939 (20°)
Ionone		127° (12 mm)	0.935 (20°)

Diacetyl (butanedione)	$CH_3COCOCH_3$	88°	0.9734 (22°)
Acetylacetone (2,4-pentanedione)	$CH_3COCH_2COCH_3$	137°	0.987 (15°)
Acetonylacetone (2,5-hexanedione)	$CH_3COCH_2CH_2COCH_3$	194°	0.969 (20°)

Dihydroresorcinol (1,3-cyclohexanedione) or cyclohexene-ol-1-one-3		—	—

		Melting Point.	
Benzoquinone (cyclohexadiene-1,4-dione-3,6)		115.7°	1.31
Benzil (diphenyl-ethanedione)	$C_6H_5COCOC_6H_5$	95°	—

1, 4 Naphthoquinone		125°	—
1, 2 Naphthoquinone		115–120°	—
Anthraquinone		273°	—
Phenanthrenquinone		205°	—

Aldehydes  $\left(R-\overset{\overset{\displaystyle O}{\|}}{C}-H\right)$ and **Ketones**  $\left(R-\overset{\overset{\displaystyle O}{\|}}{C}-R\right)$ have already been referred to as the first oxidation products of primary and secondary alcohols respectively. This method of preparation for them is the simplest and most common. The oxidizing agent usually employed is chromic acid, or a mixture of potassium or sodium pyrochromate and sulphuric acid. Alkaline oxidizing agents can rarely be used, as aldehydes, especially, are sensitive toward alkalies.

Nomenclature. — Aldehydes are named, officially, by adding "-al," and ketones by adding "-one" to the name of the hydrocarbon from which they are derived. The older names for the aldehydes, which are still more generally used, are derived from the name of the acid which results from their further oxidation. Thus the aldehyde from ethyl alcohol is called acetaldehyde because by further oxidation it gives acetic acid. Ketones are very often named by means of the groups connected by the carbonyl group; thus pentanone–2, $CH_3COCH_2CH_2CH_3$, is called methyl propyl ketone.

Formaldehyde (methanal), CH_2O, is formed by passing a current of air through methyl alcohol heated to 40°—50°, and conducting the resulting mixture of vapors over a heated copper spiral. It is also formed by the incomplete combustion of vapors of methyl alcohol in contact with platinum gauze or platinized asbestos. For disinfecting purposes, specially constructed lamps, based on this principle, have been devised.

Formaldehyde is a gas at ordinary temperatures, but may be condensed to a liquid which boils at $-21°$. In pure condition it readily passes over into a polymeric form called *oxymethylene* or *metaformaldehyde*, $(CH_2O)_x$. In dilute solutions, however, it exists in the simple form CH_2O, or perhaps, in part, as $CH_2(OH)_2$.

Formaldehyde combines directly with ammonia in aqueous solutions, to form *hexamethylene tetramine*.

$$6\,CH_2O + 4\,NH_3 = (CH_2)_6N_4 + 6\,H_2O.$$

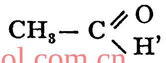
The name is unfortunate, as it is liable to confusion with the common name for an amine derived from cyclohexane.

Under the action of lime-water formaldehyde condenses to form a sugar, *α-acrose* ($C_6H_{12}O_6$) (p. 363). From the ease with which formaldehyde undergoes condensation, and from the fact that it may be considered as a reduction product of carbonic acid, it has been suggested that formaldehyde may be the first step in the formation of starch and other carbohydrates in the leaves of plants. (Baeyer, *Ber. chem. Ges.* **3**, 67; Wurtz, *Ibid.* **5**, 534; Reinke, *Ibid.* **14**, 2148; Loew, *Ibid.* **22**, 482; *J. prakt. Chem.* [2] **33**, 344.)

Formaldehyde, both as a gas and in solution, is a powerful germicide, and is extensively used as a disinfectant and food preservative. The commercial aqueous solution is known as *formaline*.

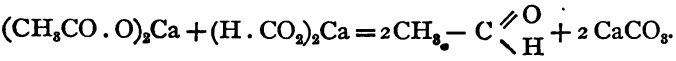
In a dilute alkaline solution, hydrogen peroxide oxidizes formaldehyde quantitively to a formate.

$$CH_2O + NaOH + H_2O_2 = NaHCO_2 + 2\,H_2O.$$

Acetaldehyde (ethanal),  $CH_3-C\begin{matrix} /\!\!/ O \\ \diagdown H \end{matrix}$, is prepared by oxidizing ethyl alcohol with sodium or potassium pyrochromate and sulphuric acid.

$$3\,C_2H_6O + Na_2Cr_2O_7 + 4\,H_2SO_4 = 3\,C_2H_4O + 2\,NaCr(SO_4)_2 + 7\,H_2O.$$

It may also be prepared by heating a mixture of calcium acetate and formate:



$$(CH_3CO\,.\,O)_2Ca + (H\,.\,CO_2)_2Ca = 2CH_3-C\begin{matrix} /\!\!/ O \\ \diagdown H \end{matrix} + 2\,CaCO_3.$$

Ordinary alcohol undergoes partial oxidation in contact with heated platinum and air, forming acetaldehyde in the same manner that formaldehyde is formed from methyl alcohol.

Acetaldehyde is a colorless liquid with a very penetrating, characteristic odor. It boils at 21°, and has a specific gravity of 0.795 at 10°.

Structure of Acetaldehyde.—The view held of the structure of acetaldehyde depends, in the first place, on the ease with which it is oxidized to acetic acid.

$$C_2H_4O + O = C_2H_4O_2.$$

Since sodium acetate gives methane when heated with sodium hydroxide, it must contain all of its hydrogen atoms combined with one of the carbon atoms, that is, it contains a methyl group, and the reaction may be written,

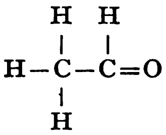
$$CH_3CO_2Na + NaOH = CH_4 + CO_3Na_2.$$

It follows from this that acetaldehyde also contains a methyl group and has the structure, $CH_3\,.\,CHO$.

It still remains to determine the structure of the group CHO, which is characteristic of all aldehydes. The structure of this group is established by the action of phosphorus pentachloride upon it.

$$CH_3CHO + PCl_5 = \underset{\text{Ethylidene chloride.}}{CH_3CHCl_2} + POCl_3.$$

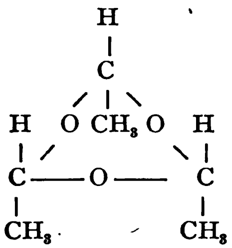
It appears from this reaction that two chlorine atoms may take the place of the oxygen atom, and from this we seem to be justified in the conclusion that this oxygen atom is doubly united with carbon. The full structure is, therefore,

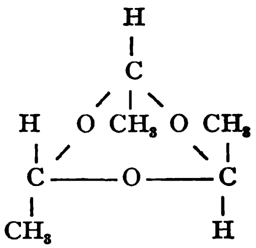


$$\begin{array}{ccccc} & H & & H & \\ & | & & | & \\ H- & C & - & C & =O \\ & | & & & \\ & H & & & \end{array}$$

The double union between carbon and oxygen may be looked upon in somewhat the same light as a double union between carbon atoms (p. 79). Oxygen in this condition occupies a greater atomic volume than when singly united with carbon or other atoms (p. 41), and the aldehyde (or ketone) group reacts very easily with a great variety of substances. In other words, a double union is weaker than a single one.

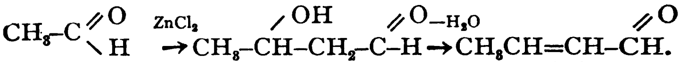
Polymeric Forms. — The addition of a small amount of hydrochloric or sulphuric acid causes acetaldehyde to change to a polymeric form, *paraldehyde* $(C_2H_4O)_3$ which boils at 125° and has a specific gravity of 0.99925 at 15°. At 0° a very little gaseous hydrochloric acid will convert acetaldehyde partly into *metaldehyde*, $(C_2H_4O)_3$, a solid compound which sublimes without melting at 112°–115°. The polymerization is, in both cases, accompanied by an evolution of heat. Since both paraldehyde and metaldehyde can be converted back into ordinary aldehyde by heat, or by distilling with a little sulphuric acid, it seems probable that the molecule is held together by means of oxygen atoms rather than by carbon, and the structure is most likely,





By this method of writing the formulae it is intended to indicate that in one polymer the three methyl groups are on the same side of the plane of the ring of carbon and oxygen atoms, while in the other two methyl groups are on one side of the plane of the ring, and one on the other. Which formula represents the structure of paraldehyde and which the structure of metaldehyde is, at present, merely a matter of conjecture.

Condensation of Aldehyde. — Under the influence of zinc chloride, or of an aqueous solution of potassium carbonate, acetaldehyde condenses to aldol, $C_4H_8O_2$. In this case the condensation has taken place between the carbon atom of the aldehyde group and that of a methyl group in the second molecule of the aldehyde. This is proved by the following relations Aldol, when distilled, gives crotonaldehyde, C_4H_6O; this, by oxidation, gives crotonic acid, $C_4H_6O_2$, and this, by reduction, normal butyric acid, which has the structure $CH_3CH_2CH_2CO_2H$. These relations can be most satisfactorily explained by the structural formulae which follow:



$$CH_3-C\overset{/\!\!/O}{\underset{\diagdown H}{}} \xrightarrow{ZnCl_2} CH_3-\overset{\diagup OH}{CH}-CH_2-\overset{/\!\!/O}{C}-H \xrightarrow{-H_2O} CH_3CH=CH-\overset{/\!\!/O}{CH}.$$

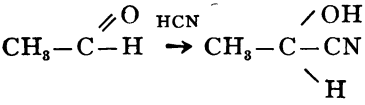
Aldol (Butanalol—3). Crotonic aldehyde.

$$\xrightarrow{O} CH_3CH=CH-CO_2H \xrightarrow{2H} CH_3CH_2CH_2CO_2H.$$

Crotonic acid. Butyric acid.

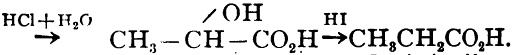
It should be noticed that in this, and in other condensations,* one molecule divides itself into two parts (here H and $-CH_2-C\begin{matrix}/\!\!/O\\ \diagdown H\end{matrix}$) which add themselves respectively to the oxygen and carbon of the aldehyde groups. Such condensations are not only useful in many organic syntheses, but doubtless, also, play an important part in the life processes of plants and animals.

Derivatives of Acetaldehyde.—Acetaldehyde combines directly with hydrocyanic acid to form a compound called the *cyanhydrin* of acetaldehyde. In this the carbon of the hydrocyanic acid is combined directly with the carbon of the aldehyde group, since hydrochloric acid and water convert it into lactic acid, and lactic acid, in turn, can be reduced to propionic acid by means of hydriodic acid.



$$CH_3-\overset{/\!\!/O}{C}-H \xrightarrow{HCN} CH_3-\overset{\diagup OH}{\underset{\diagdown H}{C}}-CN$$

Acetaldehyde cyanhydrin.



$$\xrightarrow{HCl+H_2O} CH_3-\overset{\diagup OH}{CH}-CO_2H \xrightarrow{HI} CH_3CH_2CO_2H.$$

Lactic acid. Propionic acid.

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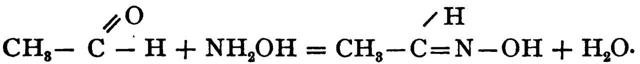
* Some authors use the term "condensation" exclusively of reactions in which carbon unites with carbon. Such a narrowing in the use of the term does not seem desirable. It is used here and elsewhere to express the combination of two molecules into one, with or without the simultaneous or subsequent elimination of water, hydrochloric acid or some other simple compounds.

The reactions here given are very generally useful for the preparation of α-hydroxy * acids from aldehydes and ketones.

Acetaldehyde combines directly with ammonia, to form a well crystallized compound, *aldehyde ammonia*, which probably has the structure, $CH_3-\overset{\diagup OH}{\underset{\diagdown H}{C}}-NH_2$. Dilute acids readily regenerate aldehyde from this compound, and it may be used in the preparation of pure aldehyde.

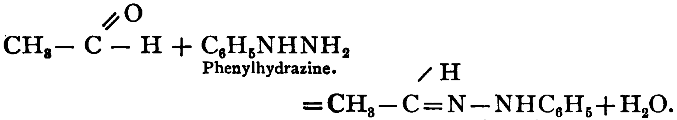
Acetaldehyde combines with acid sodium sulphite to form a double compound which, from analogy, is probably, $CH_3-\overset{\diagup OH}{\underset{\diagdown H}{C}}-SO_3Na$. As similar double compounds with other aldehydes and ketones often crystallize well, they are used, in many cases, for the purpose of purifying these bodies.

Acetaldehyde reacts with hydroxylamine to form an *oxime*, with phenylhydrazine to form a *hydrazone* and with semicarbazine to form a *semicarbazone*.



$$CH_3-\overset{/\!/ O}{C}-H + NH_2OH = CH_3-\overset{\diagup H}{C}=N-OH + H_2O.$$

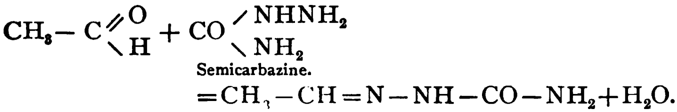
Acetaldoxime.



$$CH_3-\overset{/\!/ O}{C}-H + C_6H_5NHNH_2 = CH_3-\overset{\diagup H}{C}=N-NHC_6H_5+H_2O.$$

Phenylhydrazine.

Hydrazone of acetaldehyde.



$$CH_3-C\begin{matrix}/\!/ O\\ \diagdown H\end{matrix} + CO\begin{matrix}\diagup NHNH_2\\ \diagdown NH_2\end{matrix} = CH_3-CH=N-NH-CO-NH_2+H_2O.$$

Semicarbazine.

Semicarbazone of acetaldehyde.

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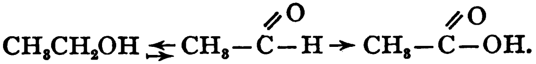
* Groups which are combined with the carbon atom which is adjacent to the carboxyl group are said to be in the α-position ; groups combined with the second carbon atom are in the β-position ; with the third, γ ; with the fourth, δ ; with the fifth, ε ; with an end carbon atom ω.

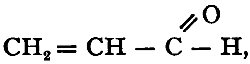
The oximes, hydrazones, and semicarbazones of aldehydes and ketones are very often used for purposes of identification, as they are usually crystalline and easily purified.

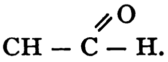
Oxidation and Reduction. — Acetaldehyde may be reduced to ethyl alcohol, and it may be readily oxidized to acetic acid. It is, therefore, intermediate between these two substances,



$$CH_3CH_2OH \rightleftarrows CH_3-\overset{\displaystyle /\!\!/O}{C}-H \rightarrow CH_3-\overset{\displaystyle /\!\!/O}{C}-OH.$$

Many other aldehydes of the marsh-gas series are known, but their general methods of preparation and chemical properties resemble those of acetaldehyde so closely as to require no special mention.



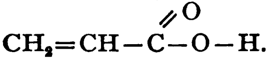


Acroleïn (propenal), $CH_2=CH-\overset{\displaystyle /\!\!/O}{C}-H$, is the first aldehyde of the ethylene series. An aldehyde of this series containing but two carbon atoms would have the structure, $CH-\overset{\displaystyle /\!\!/O}{C}-H$. The study of carbon compounds containing a bivalent carbon atom seems to indicate that such compounds can have an independent existence only when the atom or group combined with the carbon atom is strongly negative, as in the compounds CO, $C=NH$ and a few others. When the group is less negative, as in the case under consideration, the bivalent carbon atom has so great an affinity for other atoms or groups as to cause the immediate polymerization of the compound.

Acroleïn is prepared from glycerol by distilling it with acid potassium sulphate. It is also formed in small amount by the destructive distillation of fats, and is one cause of the disagreeable odor caused by heating oils and fats to a high temperature. The formation results from the abstraction of water from glycerol. This would naturally give an unsaturated alcohol,

$$CH_2OH,CHOH,CH_2OH - 2H_2O = CH_2{=}C{=}CHOH,$$

but, if such an alcohol is formed at all, it immediately rearranges itself to form the aldehyde (p. 180). Acroleïn is a liquid which boils at 52.4°. It has a penetrating, irritating odor, and affects the eyes strongly. Acroleïn may be reduced to allyl alcohol, and may be oxidized to acrylic acid,



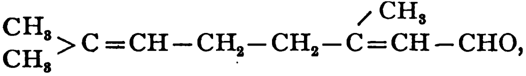
$CH_2{=}CH-\overset{/\!/O}{C}-O-H$. The presence of the double union, which is easily attacked by the oxidizing agent, makes the oxidation difficult, and it is practically better to prepare dibromacroleïn,

$CH_2BrCHBr\overset{/\!/O}{CH}$, and oxidize this to di-dibrompropionic acid, $CH_2BrCHBrCO_2H$. The latter yields acrylic acid by reduction. This case furnishes an excellent illustration of the manner in which indirect, and apparently roundabout methods are often used to advantage in the preparation of organic compounds.

Acroleïn does not combine with acid sodium sulphite.

Crotonic Aldehyde (**2-butenal**), $CH_3-CH{=}CH-CHO$, has been incidentally mentioned in connection with *aldol* (p. 177).

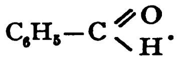
Geranial or **Citral** (**2,6-dimethyl-2,6-octadienal**),



$$\begin{matrix}CH_3\\CH_3\end{matrix}{>}C{=}CH-CH_2-CH_2-\overset{/CH_3}{C}{=}CH-CHO,$$

is found in oil of lemons and of citrons, and is prepared by the oxidation of the corresponding alcohol, *geraniol*. Geraniol is found in geranium oil and oil of roses. Geranial when heated to 170° with $KHSO_4$ condenses to cymene. The condensation is similar to the formation of aldol (p. 177), but with the difference that the condensation takes place within the same molecule. It is to be noticed that the ring which results contains *six* carbon atoms and that similar condensations often occur in which the resulting ring contains five or six atoms.

Geranial is of especial interest, also, because of its use in the preparation of *ionone*, the artificial oil of violets.

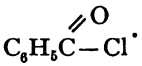
Benzaldehyde (Oil of Bitter Almonds),  $C_6H_5-C\begin{matrix}\nearrow O \\ \searrow H\end{matrix}$.

Amygdalin, a glucoside which is found in bitter almonds, peach stones, and several other vegetable substances, undergoes fermentation under the influence of *emulsin*, a soluble ferment usually associated with amygdalin, and is decomposed into benzaldehyde, glucose, and hydrocyanic acid.

$$\underset{\text{Amygdalin.}}{C_{20}H_{27}NO_{11}} + 2\,H_2O = C_6H_5CHO + HCN + 2\,\underset{\text{Glucose.}}{C_6H_{12}O_6}.$$

Benzaldehyde is prepared commercially by heating benzalchloride, from toluene, with milk of lime.

$$C_6H_5CHCl_2 + Ca(OH)_2 = C_6H_5CHO + CaCl_2 + H_2O.$$

It may also be prepared by oxidizing benzyl chloride, $C_6H_5CH_2Cl$, with nitrate of lead or barium, or by the reduction of benzoyl chloride,  $C_6H_5\overset{\nearrow O}{C}-Cl$.

Benzaldehyde is an oil which solidifies at −13.5° and boils at 179°. Its specific gravity = 1.0504 at 15°. It has a pleasant odor, and is used for flavoring and in perfumes. It is used also in the manufacture of colors of the malachite green group, and is extensively employed in the synthesis of organic compounds.

Benzaldehyde oxidizes readily to benzoic acid, if exposed to the air, but the rate of oxidation is much lessened by the presence of a little hydrocyanic acid.

Chlorine converts benzaldehyde into benzoyl chloride, $C_6H_5C\begin{matrix}/\!\!/ O\\ \diagdown Cl\end{matrix}$, a reaction which is rather unusual for aldehydes, but one which is of great interest because of its use by Wöhler and Liebig in their classical study of the radical benzoyl, C_6H_5CO (*Ann. Chem.* (Liebig), **3**, 262).

Benzaldoxime, $C_6H_5CH = N-OH$, is of especial interest, because it exists in two forms which are supposed to be stereoisomers. The α-benzaldoxime, or *anti-benzaldoxime*, is formed by the action of hydroxyl amine on benzaldehyde. It melts at 35°. The β-benzaldoxime or *syn-benzaldoxime* is formed by the action of hydrochloric acid on a solution of the α-oxime in ether. It melts at 128°–130°.

Stereoisomerism of Nitrogen Compounds. — To explain the isomerism of these and of a number of other oximes Hantzsch and Werner (*Ber. chem Ges.* **23**, 2764 (1890)) have proposed a hypothesis which is stated as follows:

"The three valences of the nitrogen atom are, in certain compounds, directed toward the corners of a tetrahedron (which is, in any case, not a regular one), whose fourth corner is occupied by the nitrogen atom itself."

This idea is most clearly represented, graphically, by picturing the center of gravity of the nitrogen atom as occupying the center of a sphere, while the three valences occupy positions, not on the equator, but on a parallel of the sphere, at a, b, c, of the figure.

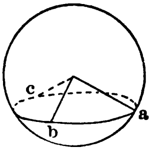
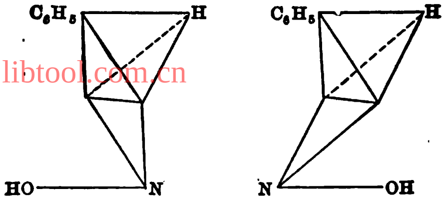


Fig. 28.

In accordance with this view the two oximes may be represented by the figures:



α-(Anti)benzaldoxime. β-(Syn)benzaldoxime.

Fig. 29.

The chief experimental basis for the theory lies in the fact that the β-oxime when treated with phosphorus trichloride gives benzonitrile, $C_6H_5\text{–}C \equiv N$, while the α-oxime gives, in part, with the same reagent, a chloride,

$$C_6H_5\text{–}CH = NCl,$$

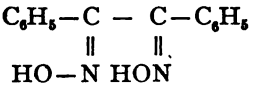
and further that the acetyl derivative,

$$C_6H_5\text{–}CH = N-O-C_2H_3O,$$

of the β compound gives benzonitrile, $C_6H_5C \equiv N$, quantitatively on warming gently with a solution of sodium carbonate, while the α compound is saponified with regeneration of the oxime by the same reagent. From these facts the conclusion is drawn that the hydrogen atom and hydroxyl group are nearer together in the β than in the α-oxime. The prefixes "syn" (together) and "anti" (opposite) are given to indicate this relation.

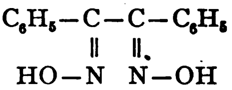
The hypothesis is an interesting and ingenious one, and is often referred to in the literature. It is, perhaps, the best explanation of these and similar compounds at present available, but it must be admitted that it rests on a far less satisfactory basis than the similar hypothesis with regard to the stereoisomerism of carbon compounds.

Condensation of Benzaldehyde. — When a solution of benzaldehyde, in dilute alcohol containing a little potassium cyanide, is boiled for a short time, the aldehyde condenses to *benzoïn*, $C_6H_5CHOHCOC_6H_5$, a compound which is part alcohol and part ketone. This is easily oxidized to *benzil*, $C_6H_5-CO-CO-C_6H_5$, a 1.2 di-ketone, or, as it is often called, an orthodiketone, which is of especial interest because it forms three isomeric dioximes. In the terms of the theory just given these are written:



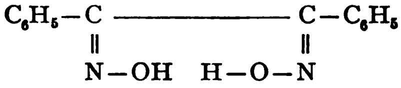
$$\begin{array}{l} C_6H_5-C \;-\; C-C_6H_5 \\ \qquad\quad \| \qquad\; \| \\ \quad HO-N\ HON \end{array}$$

α-(Amphi)-benzil dioxime, m.p. 237°.



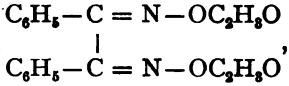
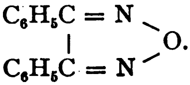
$$\begin{array}{l} C_6H_5-C-C-C_6H_5 \\ \qquad\quad \| \quad\; \| \\ \quad HO-N\ \ N-OH \end{array}$$

β-(Anti)-benzil dioxime, m.p. 206°.

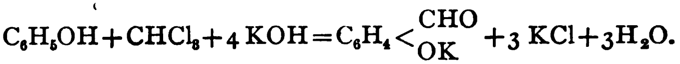


$$\begin{array}{l} C_6H_5-C \text{———————} C-C_6H_5 \\ \qquad\quad \| \qquad\qquad\qquad \| \\ \qquad N-OH \quad H-O-N \end{array}$$

γ-(Syn)-benzil dioxime, m.p. 164°–166°.

The configuration assigned to the γ-dioxime is based on the fact that its diacetyl derivative,  $\begin{array}{l} C_6H_5-C=N-OC_2H_3O \\ \quad\;\, | \\ C_6H_5-C=N-OC_2H_3O \end{array}$, yields, on saponification, an anhydride, *diphenylfurazane*,  $\begin{array}{l} C_6H_5C=N \searrow \\ \quad | \qquad\quad\;\; O. \\ C_6H_5C=N \nearrow \end{array}$ The configurations of the α- and β-dioximes are based on their conduct with phosphorus pentachloride. Some transformations of the compounds are not, however, consistent with the configurations which are given.

Salicylic Aldehyde (o-hydroxybenzaldehyde). $C_6H_4<\begin{matrix} CHO & 1 \\ OH & 2 \end{matrix}$. When a mixture of phenol and chloroform is warmed with a solution of caustic potash, both o- and p-*hydroxybenzaldehyde* are formed. The former is easily volatile with water vapor, and can be separated by that means.



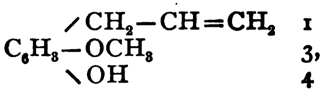
$$C_6H_5OH+CHCl_3+4\,KOH=C_6H_4{<}\begin{array}{l}CHO\\OK\end{array}+3\,KCl+3H_2O.$$

Salicylic aldehyde boils at 196°, and has a specific gravity of 1.172 at 15°. It can be easily reduced to the corresponding alcohol, *saligenin*, $C_6H_4{<}\begin{array}{l}CH_2OH\\OH\end{array}$, or oxidized to the corresponding acid, *salicylic acid.*

The reaction given for the preparation of salicylic aldehyde is known as the Reimer-Tiemann reaction (*Ber. d. chem. Ges.* 9, 423, 824; 10, 63, 213), and has been useful in many syntheses. The aldehyde group always enters in either the ortho or the para position with regard to the hydroxyl group.

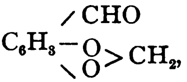
Vanillin, $C_6H_3{-}\begin{array}{ll}\diagup CHO & 1\\ OCH_3 & 3,\\ \diagdown OH & 4\end{array}$ the active principle of vanilla, has been prepared by this means from *guaiacol*, or the monomethylether of o-dihydroxybenzene, $C_6H_4{<}\begin{array}{ll}OCH_3 & 1\\OH & 2\end{array}$. Vanillin crystallizes in needles which melt at 81°. Since the aldehyde group, from what has been said, must be in either the ortho or para position with regard to the hydroxyl group, and since vanillin gives *protocatechuic acid*, $C_6H_3{-}\begin{array}{ll}\diagup CO_2H & 1\\ OH & 3,\\ \diagdown OH & 4\end{array}$ by fusion with caustic potash, the structure given above is established. (In this and similar cases the student should study the relations till he sees the force of the proof given.)

Commercially vanillin is prepared from *eugenol*,

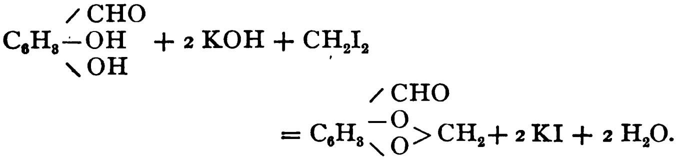


$$C_6H_3{-}\begin{array}{ll}\diagup CH_2{-}CH{=}CH_2 & 1\\ OCH_3 & 3,\\ \diagdown OH & 4\end{array}$$

an oil found in a number of different plants. (*Ber. d. chem. Ges.* 9, 273.)

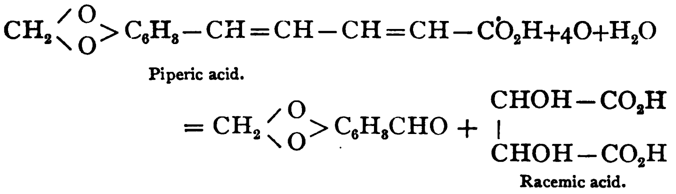


Piperonal, $C_6H_3\begin{array}{l}\diagup CHO\\ -O\\ \diagdown O\end{array}\!\!>CH_2$, has been prepared by heating protocatechuic aldehyde with methylene iodide and caustic potash,



$$C_6H_3\begin{array}{l}\diagup CHO\\ -OH\\ \diagdown OH\end{array} + 2\,KOH + CH_2I_2 = C_6H_3\begin{array}{l}\diagup CHO\\ -O\\ \diagdown O\end{array}\!\!>CH_2 + 2\,KI + 2\,H_2O.$$

Piperonal is prepared commercially by the oxidation of *piperic* acid with a neutral solution of potassium permanganate. If proper precautions are taken, racemic acid (p. 333) is formed at the same time.



$$CH_2\begin{array}{l}\diagup O\\ \diagdown O\end{array}\!\!>C_6H_3-CH=CH-CH=CH-CO_2H+4O+H_2O$$

Piperic acid.

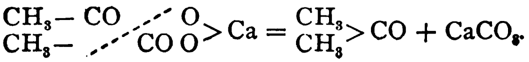
$$= CH_2\begin{array}{l}\diagup O\\ \diagdown O\end{array}\!\!>C_6H_3CHO + \begin{array}{l}CHOH-CO_2H\\ |\\ CHOH-CO_2H\end{array}$$

Racemic acid.

Piperonal melts at 37° and boils at 263°. It has an odor resembling heliotrope, and is used in perfumery.

KETONES, R—CO—R.

Acetone, or **dimethylketone (propanone),** CH_3COCH_3, is the simplest of the ketones. It is prepared by the distillation of calcium acetate:—

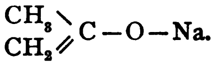


$$\begin{array}{l}CH_3-CO\\ CH_3-\end{array}\begin{array}{l}O\\ CO\,O\end{array}\!\!>Ca = \begin{array}{l}CH_3\\ CH_3\end{array}\!\!>CO + CaCO_3.$$

It is also formed by heating 2-brompropylene with mercuric oxide and acetic acid.

$$2\,CH_3-CBr=CH_2+HgO+H_2O$$
$$=HgBr_2+2\,CH_3-C(OH)=CH_2\rightarrow 2\,CH_3-CO-CH_3.$$

The reaction would lead us to expect the formation of an unsaturated alcohol, but this, if formed, rearranges itself to the ketone structure (pp. 139, 141). It is worthy of note, however, that, with metallic sodium, acetone gives an unstable compound which, from its conduct, has the structure

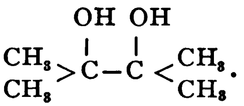


$$\begin{matrix}CH_3\diagdown\\CH_2\diagup\!\!\diagup\end{matrix}C-O-Na.$$

(Freer, *Am. Ch. J.*, **12**, 355.)

Acetone is a mobile liquid which boils at 56.5°. Phosphorus pentachloride converts it into 2.2 dichlorpropane and 2-chlorpropylene. Chromic acid oxidizes it to acetic and formic or carbonic acids. Hypochlorites convert it into chloroform and an acetate (p. 199). These facts, together with its formation from calcium acetate, furnish the basis for the view held of its structure.

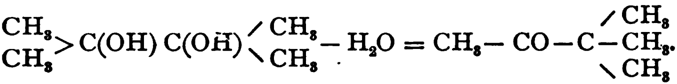
By reduction acetone gives isopropyl alcohol. There is formed at the same time a glycol called pinacone,



$$\begin{matrix}CH_3\\CH_3\end{matrix}\!>\!\overset{OH}{\underset{}{C}}-\overset{OH}{\underset{}{C}}\!<\!\begin{matrix}CH_3\\CH_3\end{matrix}.$$

Its formation can be explained by supposing that, as one hydrogen atom adds itself to the oxygen of the acetone, the group, $\begin{matrix}CH_3\\CH_3\end{matrix}\!>\!C\begin{matrix}\diagup OH,\\ \diagdown\end{matrix}$ which results, combines with another of the same sort to form the pinacone. Similar pinacones are often formed by the reduction of ketones, and, in some cases, from aldehydes.

When boiled with dilute acids pinacone undergoes a rearrangement, with loss of water, forming a *pinacoline*.

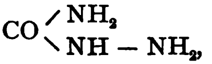


$$\begin{matrix}CH_3\\CH_3\end{matrix}\!>C(OH)\,C(OH)<\!\begin{matrix}CH_3\\CH_3\end{matrix} - H_2O = CH_3-CO-C\begin{matrix}\diagup CH_3\\-CH_3.\\\diagdown CH_3\end{matrix}$$

Dimethylbutanone.

In this case, one methyl group must pass from combination with one carbon atom to combination with the one adjacent. While rearrangements like this do not often occur, they are sufficiently frequent to furnish a warning against hasty conclusions with regard to the structure of a given compound, when based on only a few relations to other substances.

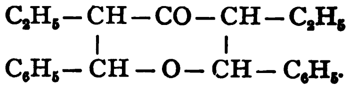
Derivatives of Acetone. — Acetone combines with acid sodium sulphite to form a double compound, $C_3H_6O.HNaSO_3$; with hydrocyanic acid to form a cyanhydrin $\begin{matrix}CH_3\\CH_3\end{matrix}\!>C<\!\begin{matrix}OH\\CN\end{matrix}$, which gives, with hydrochloric acid, hydroxyisobutyric acid, $\begin{matrix}CH_3\\CH_3\end{matrix}\!>C<\!\begin{matrix}OH\\CO_2H\end{matrix}$; with hydroxylamine to form *acetoxime*, $\begin{matrix}CH_3\\CH_3\end{matrix}\!>C=NOH$; with phenyl hydrazine to form a *phenyl hydrazone*, $\begin{matrix}CH_3\\CH_3\end{matrix}\!>C=N-NHC_6H_5$; and with semicarbazine,



$$CO<\!\begin{matrix}NH_2\\NH-NH_2,\end{matrix}$$

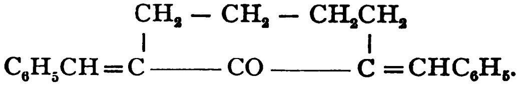
to form a semicarbazone, $\begin{matrix}CH_3\\CH_3\end{matrix}\!>C=N-NH-CO-NH_2$ In the formation of these compounds the analogy between ketones and aldehydes is so close that no further consideration of them is required.

Acetone condenses with benzaldehyde, in presence of sodium hydroxide, in aqueous or alcoholic solution, to form either *benzalacetone*, $C_6H_5CH=CH\text{-}CO\text{-}CH_3$, or *dibenzalacetone*, $C_6H_5CH=CH\text{-}CO\text{-}CH=CH\,C_6H_5$. A similar condensation takes place between benzaldehyde and other ketones containing a methyl or a methylene (CH_2) group adjacent to the carbonyl. We may suppose that there is at first a simple addition to the benzaldehyde, followed by loss of water. Open chain ketones also sometimes condense with two molecules of benzaldehyde, giving a *hydropyrone* * derivative. Thus dipropylketone, $CH_3CH_2CH_2CO\,CH_2CH_2\text{-}CH_3$, gives diethyldiphenylhydropyrone,



$$\begin{array}{l} C_2H_5-CH-CO-CH-C_2H_5 \\ \qquad\quad | \qquad\qquad\;\; | \\ C_6H_5-CH-O-CH-C_6H_5. \end{array}$$

Cyclic ketones give no similar compounds, but give, instead, the simple condensation products. Thus *suberone* gives dibenzalsuberone,



$$\begin{array}{l} \qquad\qquad\quad CH_2-CH_2-CH_2CH_2 \\ \qquad\qquad\quad | \qquad\qquad\qquad\quad\; | \\ C_6H_5CH=C——CO——C=CHC_6H_5. \end{array}$$

(Vorländer, *Ber. d. chem. Ges.* 30, 2261.)

These condensations are to be looked upon as closely related to the "aldol" condensation (p. 177) on the one hand, and to Perkins's synthesis (p. 244) on the other. The condensing agent most suitable for a particular case varies greatly. Among those which have been used may be mentioned, hydrochloric acid, sodium hydroxide, sodium ethylate, glacial acetic acid, acetic anhydride, sodium acetate and zinc chloride, and sulphuric acid. Such condensations

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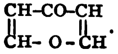
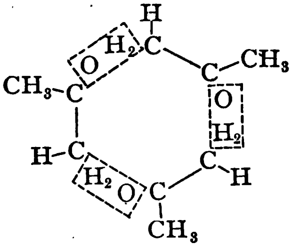
* The mother substance, *pyrone*, has the structure

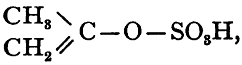


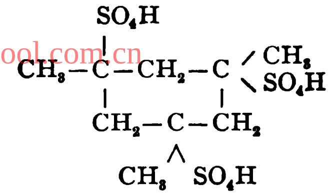
$$\begin{array}{l} CH\text{-}CO\text{-}CH \\ \| \qquad\quad \| \\ CH\text{-}O\text{-}CH. \end{array}$$

have become very useful for synthetical purposes, for the determination of the structure of ketones, and for their characterization.

Formation of Mesitylene. — If acetone is mixed with concentrated sulphuric acid, and the mixture distilled after standing for some time, from ten to twenty per cent of it condenses to mesitylene.



In most, if not in all cases, the condensing agent doubtless unites at first with the aldehyde or ketone to form intermediate products which react more readily than the original compounds, but the nature of the intermediate products is usually not clear. The following explanation of the formation of mesitylene has been given by Michael (*J. prak. Ch.* 60, 132). He supposes that propenyl sulphuric acid,  $\begin{matrix}CH_3\diagdown\\CH_2/\!/\end{matrix}C-O-SO_3H$, is at first formed by the addition of sulphuric acid to the acetone, followed by the splitting off of a molecule of water. In this compound he supposes the central carbon atom to be strongly negative, and the carbon atom of the methylene group to be comparatively positive in character. This leads to a polymerization which results from the combination of each positive carbon atom with a negative atom of another molecule, giving the compound,

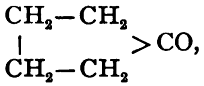


This, by loss of sulphuric acid, would give mesitylene. The idea that in additions and condensations positive atoms are attracted to negative ones, and *vice versa*, is of very general application. Thus, in the addition of hydrocyanic acid to aldehydes and ketones, compounds of the structure $=C\genfrac{}{}{0pt}{}{\diagup OH}{\diagdown CN}$, and never of the structure $=C\genfrac{}{}{0pt}{}{\diagup OCN}{\diagdown H}$, are formed, because the positive hydrogen is attracted by the negative oxygen, while the negative cyanogen is attracted by the *relatively* positive carbon.

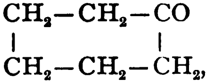
Mesityl Oxide, $\genfrac{}{}{0pt}{}{CH_3}{CH_3}{>}C=CH-CO-CH_3$, and **Phorone,** $\genfrac{}{}{0pt}{}{CH_3}{CH_3}{>}C=CH-CO-CH=C\genfrac{}{}{0pt}{}{\diagup CH_3}{\diagdown CH_3}$, may also be obtained by the condensation of acetone under proper conditions.

Other aliphatic ketones need not be considered here.

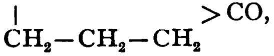
Cyclopentanone,



cyclohexanone,

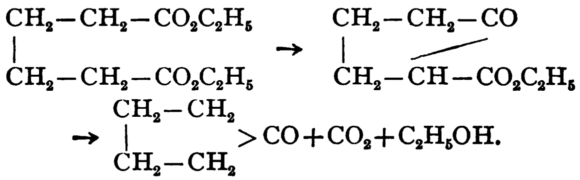


suberone or cycloheptanone,



and other ketones containing rings

of five, six or seven carbon atoms, are formed by distilling adipic, $\begin{array}{l} CH_2CH_2CO_2H \\ | \\ CH_2CH_2CO_2H, \end{array}$ pimelic, $CH_2\begin{array}{l} \diagup CH_2CH_2CO_2H \\ \diagdown CH_2CH_2CO_2H, \end{array}$ and suberic, $\begin{array}{l} CH_2CH_2CH_2CO_2H \\ | \\ CH_2CH_2CH_2CO_2H, \end{array}$ acids and their derivatives, with lime. They are also formed by the condensation of such compounds as the diethyl ester of adipic acid by means of sodium, and subsequent saponification and decomposition of the resulting cyclic ester by "ketonic decomposition" (p. 351).



Formation of Rings. — The fact that reactions of the type under consideration take place most readily when the resulting rings contain five or six atoms has led to the theory that there is an intimate connection between the formation of such rings and the nature of the carbon atom. If we assume that four atoms combined with a given carbon atom are symmetrically arranged in space, the angle between the lines joining any two of these atoms with the center of the carbon atom will be 109° 28′; that is, it will correspond to the angle between the lines joining the center of a tetrahedron, and two of its corners, or the centers of two of its sides. Some years ago Baeyer (*Ber. d. chem. Ges.* 18, 2277) proposed the hypothesis that in certain cases atoms may be drawn away from this normal position, but that there will result a greater or less strain within the resulting molecule. This will render the formation of molecules in which the departure from the normal position is considerable, more difficult, and the resulting compounds will be unstable. Now the internal angles of rings consisting of three, four, five, six and seven atoms will be:

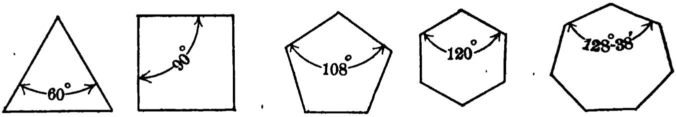


Fig. 30.

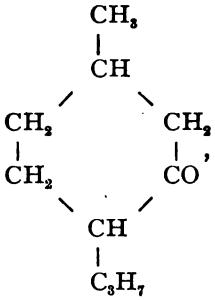
The rings of five and six atoms should, therefore, be most stable and most easily formed. This conclusion is fully justified by a study of cyclic compounds. Not only are derivatives of cyclopentane and cyclohexane more easily formed and more stable than compounds containing a ring with a smaller or larger number of carbon atoms, but mixed rings containing five or six atoms, in which one or more of the atoms of the ring may be oxygen, nitrogen or sulphur, are very common, and many such compounds are important. It is also true that a ring containing more than seven or less than five carbon atoms has not been prepared by the distillation of a calcium salt.

The cyclic ketones form, in general, the same derivatives and the same condensation products as the aliphatic ketones.

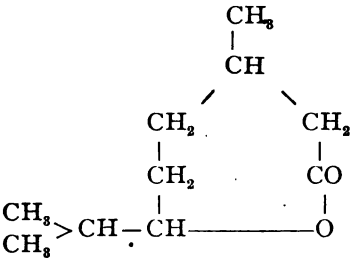
Oxidation of cyclic ketones. — When cyclic ketones are oxidized with nitric acid they give bibasic acids containing the same number of carbon atoms. Thus, cyclopentanone,

$$\begin{array}{l} CH_2-CH_2 \\ | \\ CH_2-CH_2 \end{array} > CO, \text{ gives glutaric acid, } CH_2 < \begin{array}{l} CH_2-CO_2H \\ CH_2-CO_2H \end{array}.$$

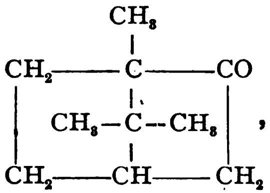
When oxidized by monopersulphuric acid, $SO_2<\begin{matrix}O-OH\\OH\end{matrix}$ (Caro's reagent), they give lactones (Baeyer and Villiger, *Ber. d. chem. Ges.* 32, 3625 (1899)). Thus, menthone,



gives the ε-lactone of 2,6 dimethyloctane-3-olic acid,

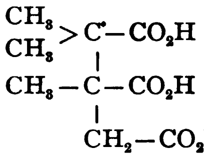


Camphor, $C_{10}H_{16}O$, is a bicyclic ketone having the structure,



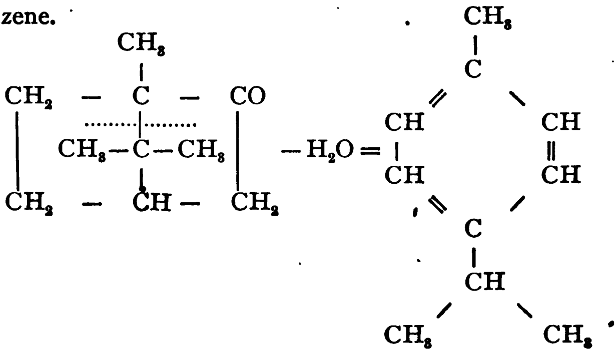
or $C_8H_{14}<\begin{matrix}CO\\|\\CH_2\end{matrix}$. Camphor is a gum obtained from the wood of the camphor tree (*Laurus Camphora*) by distillation. It melts at 176.4°, and boils at 209.1°. It sublimes slowly at ordinary temperatures, and condenses in a crystalline form. It is optically active, ordinary camphor giving the value $[\alpha]_D = +55.4° - a.q$, in which q is the amount of the solvent in 100 parts of the solution, and a is a factor dependent on the nature of the solvent.

Camphor has been prepared synthetically by the distillation of homocamphoric acid, $C_8H_{14}<\begin{matrix}CO_2H\\CH_2CO_2H\end{matrix}$, with lime. It gives borneol, $C_8H_{14}<\begin{matrix}CHOH\\|\\CH_2\end{matrix}$, by reduction, and camphoric acid, $C_8H_{14}<\begin{matrix}CO_2H\\CO_2H\end{matrix}$, by oxidation with nitric acid. Further oxidation gives camphoronic acid, (trimethyl-tricarballylic acid),



$$\begin{matrix}\begin{matrix}CH_3\\CH_3\end{matrix}>C-CO_2H\\ \quad\;|\\ CH_3-C-CO_2H\\ \quad\;|\\ \quad\;CH_2-CO_2H.\end{matrix}$$

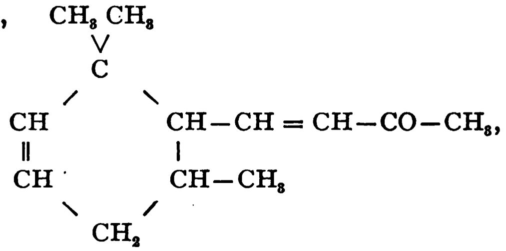
On warming with phosphorus pentoxide camphor loses water, and is converted into cymene, *p*-methyl-isopropyl benzene.



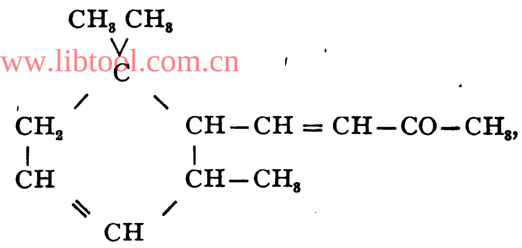
In this, and in many other cases, camphor and its derivatives undergo molecular rearrangements which are often very puzzling. The laws which govern such rearrangements are not fully understood, and the impossibility of recognizing with certainty when such changes have occurred has been a fruitful source of error in the study of the structure of compounds in the camphor and terpene group. Partly for this reason, partly because of the complex character of the compounds involved, but chiefly, perhaps, because for a long time no compound closely related to camphor was prepared by synthesis, the determination of the structure of camphor has been one of the most difficult problems in organic chemistry. Fully fifty different chemists have worked with the substance and contributed to the knowledge of its derivatives, and no less than twenty-five formulae for the body have been proposed.

Carone, *carvenone*, *fenchone*, *citral* or *geranial*, *pulegone*, *thujone* or *tanacetone*, and many other compounds isomeric with camphor are known. Most of them are not closely related to it in structure, and some of them are not ketones.

Irone,

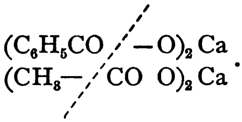


is found in violet root, and gives to it the pleasant characteristic odor. A closely related ketone, **ionone,**



has been prepared synthetically from citral as a starting-point. The odor is so nearly identical with that of irone that it is manufactured in large amounts for use as an artificial perfume. The study of these two bodies forms one of the most interesting chapters in the history of organic chemistry (Tiemann, *Ber. d. chem. Ges.* **26**, 2675–2708 (1893)).

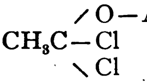
Acetophenone, or methyl-phenyl ketone, $C_6H_5COCH_3$, is the simplest aromatic ketone. It may be prepared by distilling a mixture of calcium acetate and calcium benzoate,



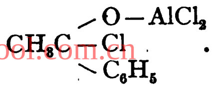
$$\begin{array}{l}(C_6H_5CO - O)_2Ca\\(CH_3 - CO\ O)_2Ca\end{array}.$$

The reaction is exactly analogous to those for the preparation of acetone and cyclopentanone.

A more satisfactory method of preparation, and one which is very general in its application, consists in adding aluminium chloride to a mixture of acetyl chloride and benzene. The acetyl chloride combines with the aluminium chloride to form a double compound, probably having the structure,



$$CH_3C\begin{array}{l}\diagup O-AlCl_2\\-Cl\\\diagdown Cl\end{array},$$

(*Ber. d. chem. Ges.* 33, 815, 1900; *Rec. Trav. Chim. Pays Bas*, **20**, 102, (1901)). This double compound reacts with the benzene, evolving hydrochloric acid and forming the compound,  $CH_3C\begin{array}{l}\diagup O-AlCl_3\\ -Cl\\ \diagdown C_6H_5\end{array}$. On adding cold water, the last compound is decomposed, giving acetophenone and an aqueous solution of aluminium chloride.

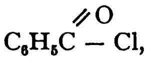
Acetophenone solidifies at a low temperature, and melts at 20.5°. It boils at 202°.

Acetophenone does not combine with acid sodium sulphite, but it forms most of the derivatives and condensation products which are characteristic of ketones.

With calcium hypochlorite it gives calcium benzoate and chloroform.

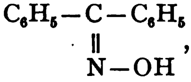
$$2C_6H_5CO\,CH_3 + 3CaO_2Cl_2 = 2C_6H_5CO\,CCl_3 + 3Ca(OH)_2.$$
$$2C_6H_5CO\,CCl_3 + Ca(OH)_2 = Ca(C_6H_5CO_2)_2 + 2CHCl_3.$$

A similar decomposition is produced by sodium hypobromite. Both reactions are analogous to the preparation of chloroform from acetone, and are general in their application (pp. 188 and 396).

Benzophenone, $(C_6H_5)_2CO$, is formed by distilling calcium benzoate, or by treating benzoyl chloride,  $C_6H_5C\begin{array}{l}/\!\!/O\\ -Cl\end{array}$, and benzene with aluminium chloride. It melts at 48°, and boils at 306.1°. As the compound can be easily obtained pure, and boils without decomposition, it is useful for determining the accuracy of thermometers.

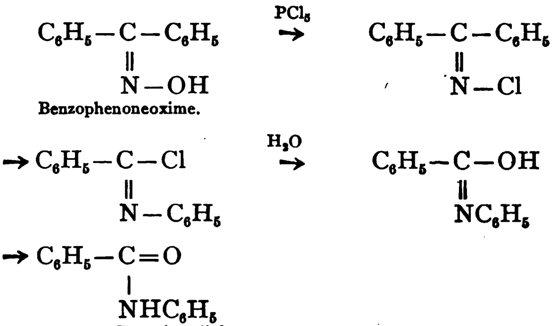
Under some conditions of preparation or of treatment, benzophenone is formed or is converted into an allotropic form, which melts at 26°. The cause of the difference between the two forms is not clearly understood, but it is probably due to a difference in molecular aggregation, and not to a difference in structure. The boiling points and chemical properties of the two forms are identical. The phenomenon is similar to that of the two forms of sulphur which melt at 114° and 120° respectively, with the difference that the point of transition for the two forms of benzophenone lies above the melting point of each, while the point of transition for sulphur lies below the melting point of each form.

Beckmann's Rearrangement.—The oxime of benzophenone,



$$\begin{array}{c} C_6H_5-C-C_6H_5 \\ \| \\ N-OH \end{array}$$

, when treated with phosphorus pentachloride and then with water, is converted quantitatively into benzoic anilide, $C_6H_5CO-NHC_6H_5$. This is known as "Beckmann's rearrangement," and is general for the ketoximes. It probably takes place in the following steps:

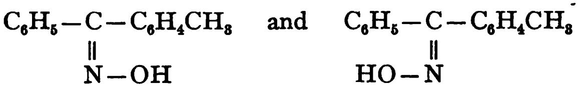


$$\begin{array}{ccc} \begin{array}{c} C_6H_5-C-C_6H_5 \\ \| \\ N-OH \end{array} & \xrightarrow{PCl_5} & \begin{array}{c} C_6H_5-C-C_6H_5 \\ \| \\ N-Cl \end{array} \\ \rightarrow \begin{array}{c} C_6H_5-C-Cl \\ \| \\ N-C_6H_5 \end{array} & \xrightarrow{H_2O} & \begin{array}{c} C_6H_5-C-OH \\ \| \\ NC_6H_5 \end{array} \\ \rightarrow \begin{array}{c} C_6H_5-C=O \\ | \\ NHC_6H_5 \end{array} & & \end{array}$$

Benzophenoneoxime.

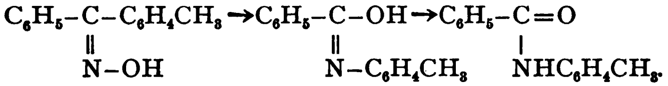
Benzoic anilide.

Unsymmetrical derivatives of benzophenone, that is, derivatives in which the two phenyl groups contain different substituents, generally give oximes which exist in two forms. A careful study of many such cases has shown that the chemical conduct of the two forms is so nearly identical as to justify the belief that each form is a true oxime, and that the difference is due to stereoisomerism dependent on the nitrogen atom (p. 183). Thus, the oxime of phenyltolylketone exists in forms represented by the formulas:



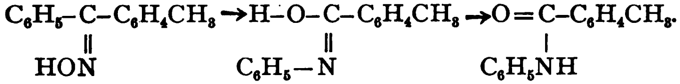
$$\begin{array}{l}C_6H_5-C-C_6H_4CH_3\\ \quad\;\;\, \|\\ \quad\;\;\, N-OH\end{array} \quad \text{and} \quad \begin{array}{l}C_6H_5-C-C_6H_4CH_3\\ \quad\;\;\, \|\\ HO-N\end{array}$$

When the two oximes are treated with phosphorus pentachloride, each undergoes the "Beckmann rearrangement." The first gives benzoic toluide,



$$\begin{array}{l}C_6H_5-C-C_6H_4CH_3\\ \quad\;\;\, \|\\ \quad\;\;\, N-OH\end{array} \rightarrow \begin{array}{l}C_6H_5-C-OH\\ \quad\;\;\, \|\\ \quad\;\;\, N-C_6H_4CH_3\end{array} \rightarrow \begin{array}{l}C_6H_5-C=O\\ \quad\;\;\, |\\ \quad\;\;\, NHC_6H_4CH_3.\end{array}$$

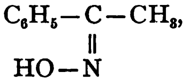
The second, on the other hand, gives toluic anilide.



$$\begin{array}{l}C_6H_5-C-C_6H_4CH_3\\ \quad\;\;\, \|\\ \;\; HON\end{array} \rightarrow \begin{array}{l}H-O-C-C_6H_4CH_3\\ \qquad\;\;\, \|\\ \; C_6H_5-N\end{array} \rightarrow \begin{array}{l}O=C-C_6H_4CH_3.\\ \quad\;\, |\\ C_6H_5NH\end{array}$$

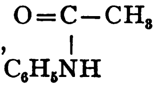
Beckmann's rearrangement serves, therefore, to distinguish between the two forms.

When the two groups combined with the carbonyl of the ketone differ greatly, the oxime usually exists in only one form. Thus, the oxime of acetophenone exists, apparently, only in the form,



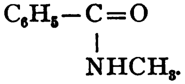
$$\begin{array}{l}C_6H_5-C-CH_3,\\ \quad\;\;\, \|\\ HO-N\end{array}$$

since it gives, by rearrangement, acetanilide,



$$\begin{array}{l}\;\; O=C-CH_3\\ \qquad\; |\\ C_6H_5NH\end{array}$$

, and not methyl benzamide,



$$\begin{array}{l}C_6H_5-C=O\\ \qquad\;\; |\\ \qquad\;\; NHCH_3.\end{array}$$

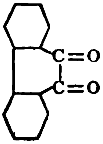
1,2-DIKETONES, R—CO—CO—R.

When ketones of the general formula R—CO—CH_2—R are treated with sodium and amyl nitrite, $C_5H_{11}NO_2$, isonitroso-

$$\begin{array}{l}CO_2H\\|\\CO_2H\end{array};\ \text{pyroracemic acid,}\ \begin{array}{l}CO-CH_3\\|\\CO_2H\end{array};\ \text{dioxytartaric acid,}$$

$$\begin{array}{l}C(OH)_2-CO_2H\\|\\C(OH)_2-CO_2H\end{array};$$

etc.), react in a similar manner. In all of these cases the ready formation of a ring containing six atoms is noticeable.



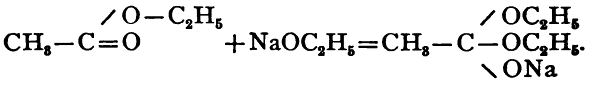
Phenanthraquinone, is readily prepared by the oxidation of phenanthrene. It melts at 205°, and distills without decomposition at a temperature above 360°. It may be further oxidized to 1,1′diphenic acid,

$$\begin{array}{l}C_6H_4-CO_2H\\|\\C_6H_4-CO_2H\end{array}.$$

1,3-DIKETONES, $(R-CO-CH_2-CO-R)$, OR β-DIKETONES.

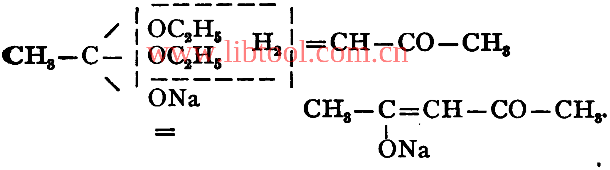
1, 3-Diketones, or β-diketones, are prepared by the condensation of ketones with esters by means of sodium ethylate. The reaction takes place readily only with ketones containing the group $-CO-CH_3$.

It is supposed that the sodium ethylate forms an addition product with the ester:



$$CH_3-C\begin{array}{l}\diagup O-C_2H_5\\=O\end{array}+NaOC_2H_5=CH_3-C\begin{array}{l}\diagup OC_2H_5\\-OC_2H_5\\\diagdown ONa\end{array}.$$

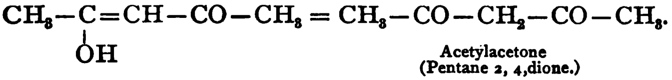
This compound then condenses with the ketone:



$$CH_3-C\begin{array}{l}\diagup\ \boxed{\begin{array}{l}OC_2H_5 \quad H_2\\ OC_2H_5\end{array}}=CH-CO-CH_3\\ \diagdown\ ONa\end{array}$$

$$= CH_3-\underset{\displaystyle ONa}{\underset{|}{C}}=CH-CO-CH_3.$$

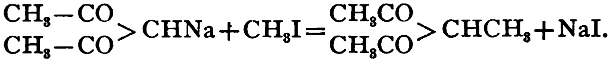
On adding an acid the unsaturated alcohol formed probably rearranges, in some cases, to form a 1,3-diketone (p. 139).



$$CH_3-\underset{\displaystyle OH}{\underset{|}{C}}=CH-CO-CH_3 = CH_3-CO-CH_2-CO-CH_3.$$

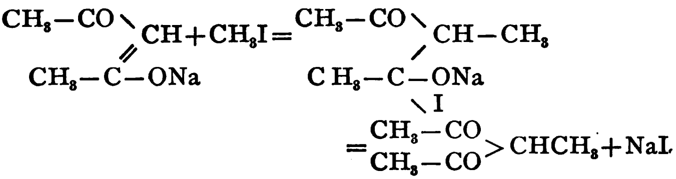
Acetylacetone
(Pentane 2, 4,dione.)

In other cases, however, the "enol" or unsaturated alcoholic form is undoubtedly retained. The 1,3-diketones containing the grouping $R-CO-CH_2-CO-R$ always have a hydrogen atom which can be replaced by metals; and in many cases such ketones are strong acids, giving a copper salt with an aqueous solution of copper acetate and even decomposing carbonates. Formerly it was often assumed that the metal in these compounds is united with the carbon atom, since compounds in which the alkyl is combined with carbon are formed from them on treatment with alkyl-halides.



$$\begin{matrix}CH_3-CO\\ CH_3-CO\end{matrix}\!>CHNa+CH_3I=\begin{matrix}CH_3CO\\ CH_3CO\end{matrix}\!>CHCH_3+NaI.$$

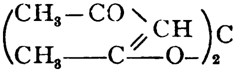
A careful study of very many related cases makes it more probable that the metallic compound is a derivative of the "enol" form, and that the reaction in question consists at first in the addition of the alkyl-halide to the double union.



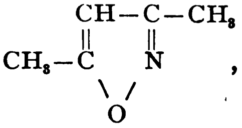
$$\begin{array}{l}CH_3-CO\diagdown\\ \qquad\qquad\quad CH+CH_3I=\\ \qquad\quad /\!\!/\\ CH_3-C-ONa\end{array}\begin{array}{l}CH_3-CO\diagdown\\ \qquad\qquad\quad CH-CH_3\\ \qquad\quad\diagup\\ CH_3-C-ONa\\ \qquad\quad\diagdown I\end{array}$$

$$=\begin{matrix}CH_3-CO\\ CH_3-CO\end{matrix}\!>CHCH_3+NaI.$$

The acid character of the 1,3-diketones is of especial interest because it has been assumed that true organic acids must contain the carboxyl group, $-\mathrm{C}\begin{smallmatrix}\diagup\!\!\diagup \mathrm{O} \\ \diagdown \mathrm{O-H}\end{smallmatrix}$. A comparison of this group with the "enol" formula of the 1, 3 diketones shows that in each case the hydroxyl group is combined with a carbon atom which is doubly united with another atom. It has recently been suggested (Vorländer, *Ber. d. chem. Ges.* 34, 1632) that the replaceable hydrogen of organic acids, and, indeed, of most inorganic acids as well, is usually connected with atoms having a similar grouping.

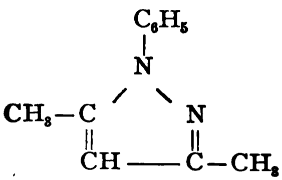
Acetylacetone, or **2,4 Pentanedione,** $CH_3-CO-CH_2-CO-CH_3$, is formed by the action of sodium, in the form of wire, upon a mixture of acetone and acetic ester (see above). It is a colorless liquid which boils at 137°. The copper salt,  $\left(\begin{matrix}CH_3-CO\diagdown \\ \qquad\qquad\quad CH \\ CH_3-C\diagup\!\!\diagup-O-\end{matrix}\right)_2Cu$, is precipitated on adding a solution of copper acetate to its aqueous solution.

The oxime of acetylacetone loses water as soon as formed, and condenses to α-γ-dimethylisoxazole,



a reaction characteristic of the β-diketones.

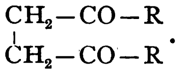
With phenyl hydrazine, $C_6H_5NHNH_2$, it gives, in a similar manner, 1-*phenyl*-3,5-*dimethyl pyrazole*,



Similar reactions, resulting in heterocyclic compounds, that is, compounds with rings containing atoms of two or more kinds, are frequent and important.

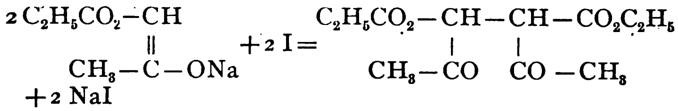
Dihydroresorcinol, $CH_2 < \begin{matrix} CH_2-CO \\ CH_2-CO \end{matrix} > CH_2$, or 1,3 **Cyclohexanedione,** has already been quite fully considered. Unlike the open chain, 1,3-diketones, it forms a dioxime and a normal phenylhydrazone. It would seem that the cyclic structure prevents, in this case, the formation of an isoxazole or pyrazole compound.

1,4-DIKETONES,



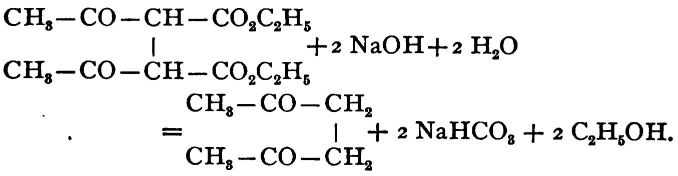
$$\begin{matrix} CH_2-CO-R \\ | \\ CH_2-CO-R \end{matrix} .$$

Acetonylacetone or 2,5-Hexanedione, $\begin{matrix} CH_2-CO-CH_3 \\ | \\ CH_2-CO-CH_3 \end{matrix}$, is the simplest of the aliphatic 1,4, or γ-diketones. When sodium acetacetic ester is treated with iodine, diacetylsuccinic ester is formed.



$$\begin{matrix} 2\,C_2H_5CO_2-CH \\ \| \\ CH_3-C-ONa \end{matrix} + 2\,I = \begin{matrix} C_2H_5CO_2-CH-CH-CO_2C_2H_5 \\ | \qquad | \\ CH_3-CO \quad CO-CH_3 \end{matrix} + 2\,NaI$$

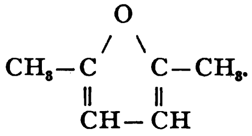
The diacetylsuccinic ester gives, on saponification with dilute sodium hydroxide, acetonylacetone.



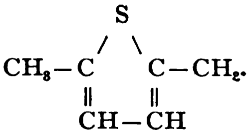
$$\begin{matrix} CH_3-CO-CH-CO_2C_2H_5 \\ | \\ CH_3-CO-CH-CO_2C_2H_5 \end{matrix} + 2\,NaOH + 2\,H_2O = \begin{matrix} CH_3-CO-CH_2 \\ | \\ CH_3-CO-CH_2 \end{matrix} + 2\,NaHCO_3 + 2\,C_2H_5OH.$$

Acetonylacetone boils at 194°, and is miscible with water, alcohol, or ether in all proportions. It is insoluble in a concentrated solution of potassium hydroxide or potassium carbonate. The last fact indicates that it is a true ketone, and distinguishes it sharply from the 1,3-diketones, which pass readily into the "enol" form (see p. 205).

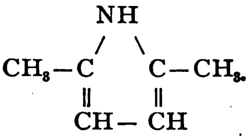
When distilled with zinc chloride acetonylacetone gives 2,5 *dimethylfurane* (or *dimethylfurfurane*),



With phosphorus pentasulphide it gives 2,5-*dimethylthiofurane* (or *dimethylthiophene*),



With alcoholic ammonia it gives 2,5-dimethylazole (or dimethylpyrrol),



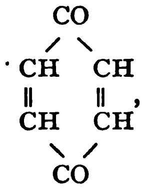
Acetonylacetone forms a dioxime and a diphenylhydrazone.

An examination of the statements of the last few pages reveals the fact that each class of aliphatic diketones forms cyclic compounds peculiar to itself, but that in each case the cyclic compounds which are most characteristic and most easily formed contain a ring of five atoms.

QUINONES.

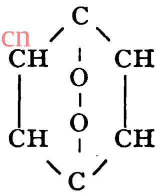
In the aromatic series there is a peculiar class of 1,4 diketones known as *quinones*. These bodies differ from ordinary ketones in so many ways that for a long time another structure was often ascribed to them. The work of Nef and of others has, however, placed their structure as ketones beyond reasonable doubt.

Quinone,



is most easily prepared by the oxidation of aniline, $C_6H_5NH_2$, by a mixture of dilute sulphuric acid and sodium pyrochromate. It is also formed by the oxidation of hydroquinone, $C_6H_4<\begin{matrix}OH & 1\\ OH & 4\end{matrix}$, p-aminophenol, $C_6H_4<\begin{matrix}OH & 1\\ NH_2 & 4\end{matrix}$, and p-diaminobenzene (p-phenylenediamine), $C_6H_4<\begin{matrix}NH_2 & 1\\ NH_2 & 4\end{matrix}$. All of these methods are general in their application, and may be used for the preparation of other quinones.

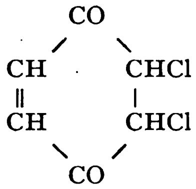
Quinone crystallizes in yellow prisms or needles which melt at 116°. It has a peculiar penetrating odor resembling that of chlorine. It acts, in many cases, as an oxidizing agent, and is itself reduced to hydroquinone. At a time when very few compounds intermediate between benzene and cyclohexane were known, the close relation between quinone and hydroquinone as well as the other properties of quinone, especially as an oxidizing agent, led most chemists to favor Graebe's peroxide formula for the body.



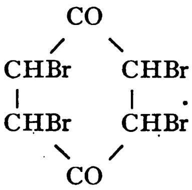
(*Zeit. f. Chem.* 3, 39 (1867)).

The following facts, however, indicate that it is a diketone:

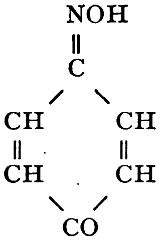
It adds directly two or four atoms of chlorine or bromine, forming such compounds as,



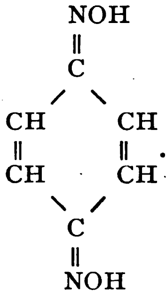
and



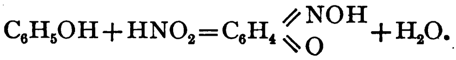
It condenses with hydroxylamine to form a monoxime and a dioxime,



and



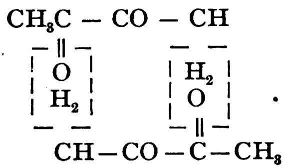
Quinone monoxime is also formed by the action of nitrous acid on phenol.



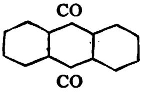
$$C_6H_5OH+HNO_2=C_6H_4{\genfrac{}{}{0pt}{}{/\!\!/NOH}{\backslash\!\!\backslash O}}+H_2O.$$

On account of this method of formation the compound is called p-nitrosophenol, and the formula, $C_6H_4 < \begin{matrix}NO\\OH\end{matrix}$, is ascribed to it. Since it gives with hydroxylamine the dioxime, $C_6H_4 \begin{matrix}\diagup N-OH\\ \diagdown N-OH\end{matrix}$, the formula representing it as an oxime seems to be more probable.

p-Xyloquinone is formed by warming butanedione (p. 203) with a dilute solution of sodium hydroxide:



It gives by reduction *dihydroxy-p-xylene*, $C_6H_2 < \begin{matrix}CH_3 & 1.\\ OH & 2.\\ CH_3 & 4.\\ OH & 5.\end{matrix}$

Anthraquinone, , is formed easily by the direct oxidation of anthracene with chromic acid. Anthraquinone is also formed by the following reactions which demonstrate its structure.

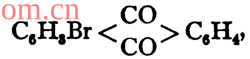
Phthalic anhydride when treated with benzene and aluminium chloride gives o-benzoylbenzoic acid:

$$C_6H_4 < \begin{matrix}CO\\CO\end{matrix} > O + C_6H_6 + AlCl_3 = C_6H_4 < \begin{matrix}CO-C_6H_5\\CO_2H\end{matrix} + AlCl_3.$$

This acid on treatment with phosphorus pentachloride gives anthraquinone:

$$C_6H_4 < \begin{matrix}CO-C_6H_5\\CO_2H\end{matrix} + PCl_5 = C_6H_4 < \begin{matrix}CO\\CO\end{matrix} > C_6H_4 + 2HCl + POCl_3$$

In a similar manner bromanthraquinone (see p. 117),



$$C_6H_3Br<\begin{matrix}CO\\CO\end{matrix}>C_6H_4,$$

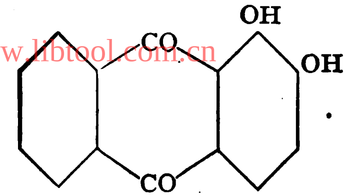
may be obtained, starting with bromphthalic anhydride. At 160°, with potassium hydroxide, bromanthraquinone yields hydroxyanthraquinone, $C_6H_3(OH)<\begin{matrix}CO\\CO\end{matrix}>C_6H_4$, and this, by oxidation with nitric acid, gives phthalic acid. Since phthalic acid is an ortho compound, and since the benzene nucleus which came from the bromphthalic acid must be the one destroyed by the oxidation, it follows that the two carbonyl groups are combined with adjacent carbon atoms in each of the benzene nuclei of anthraquinone.

Anthraquinone crystallizes in yellow needles. It melts at 273° and boils at 380°.

Alizarin. — Anthraquinone is of especial interest because of its relation to alizarin, the coloring matter of madder root which is used in dyeing for the color known as "Turkey red."

In 1868 Graebe and Liebermann discovered that by distilling alizarin with zinc dust anthracene is formed. This discovery formed the basis of further work, which finally led to the commercial manufacture of alizarin by the following steps:

Anthracene, from coal-tar, is first oxidized to anthraquinone. When this is heated with fuming sulphuric acid, anthraquinonesulphonic acid, $C_6H_4<\begin{matrix}CO\\CO\end{matrix}>C_6H_3SO_3H$, is formed; and when this is heated with sodium hydroxide and potassium chlorate the sulphonic acid group is replaced by hydroxyl and an adjacent hydrogen atom is also oxidized to hydroxyl, giving alizarin,



In madder root alizarin is found as a glucoside, $C_{20}H_{22}O_{11}$, which is decomposed by ferments or by dilute acids or alkalies.

$$C_{20}H_{22}O_{11} = C_{14}H_8O_4 + C_6H_{12}O_6 + H_2O.$$

Alizarin crystallizes in red needles. It melts at 290°, and boils at 430°. It dissolves in sodium or potassium hydroxide, giving a deep red solution from which it is reprecipitated by carbon dioxide. It forms a not very sensitive indicator for acidimetry. It is a red dye with aluminium mordants,[*] a violet dye with a ferric salt as a mordant, and a granite brown with a chromium salt.

The value of the alizarin manufactured during 1880 is given as $8,000,000. It is estimated that the manufacture of the same amount of alizarin from madder root would have cost $28,000,000.[†] In other words, in the manufacture of this single dyestuff an annual saving of $20,000,000 is effected by a method of manufacture based on the study of the structure of alizarin.

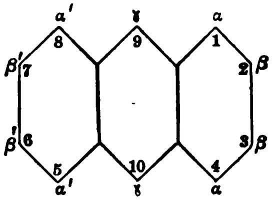
Several other dihydroxyanthraquinones are known. Of these, all having the hydroxyl groups in the ortho position toward each other are dyestuffs.

---

[*] A "mordant" is an inorganic compound which combines with a dyestuff to form an insoluble compound, called a "lake."

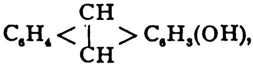
[†] Heinzerling, *Abriss der chemischen Technologie*, S. 164.

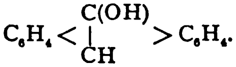
The derivatives of anthracene * are best classified by the following scheme, in which the numerals are given the preference.

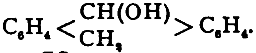


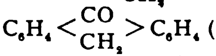
Unfortunately, actual usage frequently does not conform to this scheme, especially in naming those derivatives with substituents in positions 9 and 10.

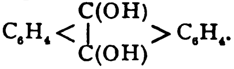
The following are the more interesting of the derivatives of anthracene: —

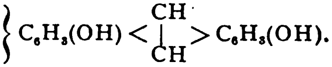
Anthrol, 
$C_6H_4<\begin{matrix}CH\\|\\CH\end{matrix}>C_6H_3(OH)$, 1 and 2 or α and β.

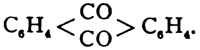
Anthranol, 
$C_6H_4<\begin{matrix}C(OH)\\|\\CH\end{matrix}>C_6H_4$.

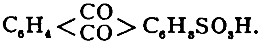
Hydroanthranol, 
$C_6H_4<\begin{matrix}CH(OH)\\CH_2\end{matrix}>C_6H_4$.

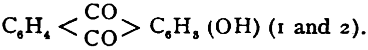
Anthranone, 
$C_6H_4<\begin{matrix}CO\\CH_2\end{matrix}>C_6H_4$ (isomeric with anthranol).

Anthrahydroquinone, 
$C_6H_4<\begin{matrix}C(OH)\\|\\C(OH)\end{matrix}>C_6H_4$.

Dioxyanthracene,†
Rufol, flavol,
Crysazol,

$\left.\right\}C_6H_3(OH)<\begin{matrix}CH\\|\\CH\end{matrix}>C_6H_3(OH)$.

Anthraquinone, 
$C_6H_4<\begin{matrix}CO\\CO\end{matrix}>C_6H_4$.

Anthraquinone, monosulphonic acid, 
$C_6H_4<\begin{matrix}CO\\CO\end{matrix}>C_6H_3SO_3H$.

Oxyanthraquinone,‡ 
$C_6H_4<\begin{matrix}CO\\CO\end{matrix}>C_6H_3\,(OH)$ (1 and 2).

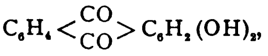
---

* While a discussion of the derivatives of anthracene does not logically belong here, this seems to be, practically, the best place for its introduction.

† More properly dihydroxyanthracene.

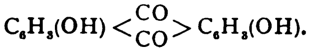
‡ Or hydroxyanthraquinone.

Dioxyanthraquinone,
Alizarin (1,2),
Purpuroxanthin (1,3),
Quinizarin (1,4),
Anthrarufin (1,5),
Crysazin (1,6)?
Benzdioxyanthraquinone (1,7),
Hystazarin (2,3),
Anthraflavic acid (2,6),
Isoanthraflavic acid (2,7),



$$C_6H_4 < \substack{CO \\ CO} > C_6H_2(OH)_2,$$

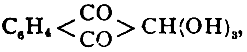
and



$$C_6H_3(OH) < \substack{CO \\ CO} > C_6H_3(OH).$$

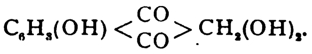
Trioxyanthraquinone,

Purpurin (1,2,4),



$$C_6H_4 < \substack{CO \\ CO} > CH(OH)_3,$$

Oxyanthrarufin (1,2,5),
Flavopurpurin (1,2,6),
Anthrapurpurin (1,2,7).

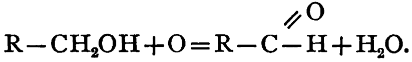


$$C_6H_3(OH) < \substack{CO \\ CO} > CH_2(OH)_2.$$

The list might be greatly extended to include nitro compounds, amines, nitroso derivatives, and many other bodies which are known.

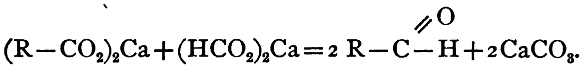
General Methods of Preparing Aldehydes.

1. Oxidation of primary alcohols:



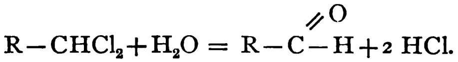
$$R-CH_2OH+O=R-\overset{/\!\!/O}{C}-H+H_2O.$$

2. Distillation of a calcium salt of an acid mixed with calcium formate:



$$(R-CO_2)_2Ca+(HCO_2)_2Ca=2\,R-\overset{/\!\!/O}{C}-H+2CaCO_3.$$

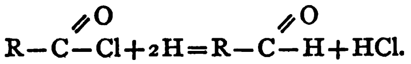
3. By boiling compounds containing the group $-CHCl_2$ with water or with water and lead oxide:



$$R-CHCl_2+H_2O = R-\overset{/\!\!/O}{C}-H+2\,HCl.$$

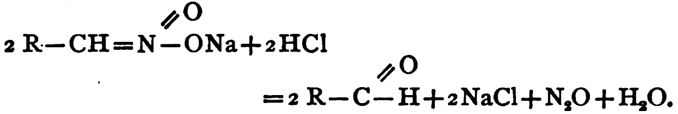
Of less importance, but still general in character, are the following:

4. By the action of nascent hydrogen on the chloride of an acid:



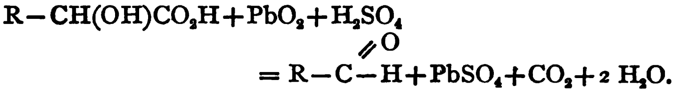
$$R-\overset{O}{\overset{/\!/}{C}}-Cl+2H=R-\overset{O}{\overset{/\!/}{C}}-H+HCl.$$

5. By treating with an acid the sodium salt of a nitroparaffin having the nitro group attached to an end carbon atom:



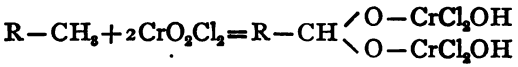
$$2\,R-CH=\overset{O}{\overset{/\!/}{N}}-ONa+2HCl$$
$$=2\,R-\overset{O}{\overset{/\!/}{C}}-H+2NaCl+N_2O+H_2O.$$

6. By warming α-hydroxy acids, containing the group R–CH(OH)CO_2H, with lead peroxide and dilute sulphuric acid:

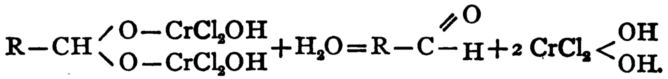


$$R-CH(OH)CO_2H+PbO_2+H_2SO_4$$
$$=R-\overset{O}{\overset{/\!/}{C}}-H+PbSO_4+CO_2+2\,H_2O.$$

7. Treatment of a hydrocarbon of the aromatic series with chromyl chloride, followed by water:



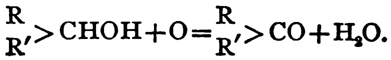
$$R-CH_3+2CrO_2Cl_2=R-CH\genfrac{}{}{0pt}{}{\diagup O-CrCl_2OH}{\diagdown O-CrCl_2OH}$$



$$R-CH\genfrac{}{}{0pt}{}{\diagup O-CrCl_2OH}{\diagdown O-CrCl_2OH}+H_2O=R-\overset{O}{\overset{/\!/}{C}}-H+2\,CrCl_2{<}\genfrac{}{}{0pt}{}{OH}{OH.}$$

General Methods of Preparing Ketones.

1. Oxidation of secondary alcohols:

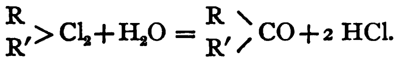


$$\genfrac{}{}{0pt}{}{R}{R'}{>}CHOH+O=\genfrac{}{}{0pt}{}{R}{R'}{>}CO+H_2O.$$

2. Distilling calcium salts of acids:

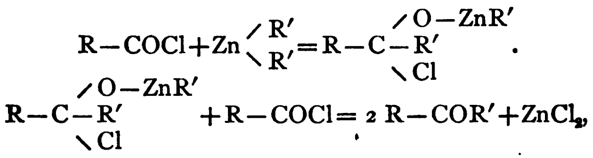
$$\begin{matrix}R-CO_2\\R'-CO_2\end{matrix}\!>Ca = \begin{matrix}R\\R'\end{matrix}\!>CO+CaCO_3.$$

3. By boiling compounds containing the group $\begin{matrix}R\\R'\end{matrix}\!>CCl_2$ with water or water and lead oxide:



$$\begin{matrix}R\\R'\end{matrix}\!>Cl_2+H_2O = \begin{matrix}R\\R'\end{matrix}\!>CO+2\,HCl.$$

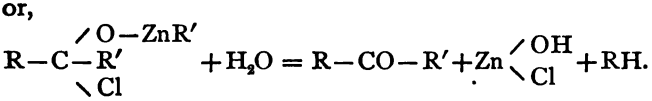
4. By treating the chloride of an acid with a zinc alkyl:



$$R-COCl+Zn\begin{matrix}/\,R'\\ \backslash\,R'\end{matrix}=R-C\begin{matrix}/\,O-ZnR'\\-R'\\ \backslash\,Cl\end{matrix}.$$

$$R-C\begin{matrix}/\,O-ZnR'\\-R'\\ \backslash\,Cl\end{matrix}+R-COCl=2\,R-COR'+ZnCl_2,$$

or,



$$R-C\begin{matrix}/\,O-ZnR'\\-R'\\ \backslash\,Cl\end{matrix}+H_2O=R-CO-R'+Zn\begin{matrix}/\,OH\\ \backslash\,Cl\end{matrix}+RH.$$

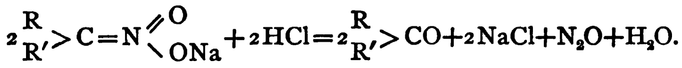
5. By treatment of the chloride of an acid with aluminium chloride and an aromatic hydrocarbon (p. 198).

6. By the "ketonic" decomposition of compounds of the type of acetacetic ester (p. 351):

$$R-CO-CH_2CO_2C_2H_5+HCl+H_2O$$
$$=R-CO-CH_3+CO_2+C_2H_5OH+HCl.$$

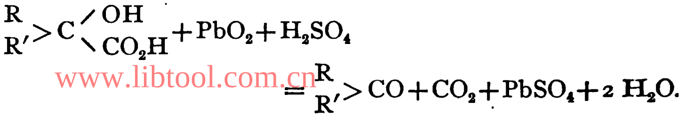
Of less importance:

7. Treatment of the metallic salt of a secondary nitro derivative with an acid:



$$2\begin{matrix}R\\R'\end{matrix}\!>C=N\begin{matrix}/\!\!/\,O\\ \backslash\,ONa\end{matrix}+2HCl=2\begin{matrix}R\\R'\end{matrix}\!>CO+2NaCl+N_2O+H_2O.$$

8. By warming an α-hydroxy acid containing the group $\begin{matrix}R\\R'\end{matrix}\!>C\begin{matrix}/\,OH\\ \backslash\,CO_2H\end{matrix}$ with lead peroxide and sulphuric acid:



$$\begin{matrix}R\\R'\end{matrix}\!>C\!\begin{matrix}\diagup OH\\ \diagdown CO_2H\end{matrix} + PbO_2 + H_2SO_4 \\ = \begin{matrix}R\\R'\end{matrix}\!>CO + CO_2 + PbSO_4 + 2\,H_2O.$$

General Characteristics of Aldehydes and Ketones.

1. Aldehydes may be reduced to primary alcohols, ketones to secondary alcohols.

2. Aldehydes may be oxidized to monobasic acids containing the same number of carbon atoms, open-chain ketones to acids containing a smaller number of carbon atoms, and cyclic ketones to bibasic acids containing the same number of carbon atoms.

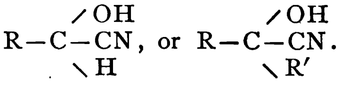
3. Aldehydes polymerize easily, ketones do not.

4. Both aldehydes and ketones condense readily with themselves and with other compounds in many ways that are useful for synthetic purposes.

5. Treatment with phosphorus pentachloride replaces the oxygen of either an aldehyde or a ketone with two chlorine atoms.

6. With hydroxylamine each forms oximes, and with phenylhydrazine, $C_6H_5NHNH_2$, semicarbazine, $NH_2-NH-CO-NH_2$, etc., each forms phenylhydrazones, semicarbazones, etc.

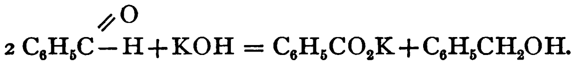
7. With hydrocyanic acid each forms cyanhydrins, or nitriles of α-hydroxy acids,



$$R-\overset{\diagup OH}{\underset{\diagdown H}{C}}-CN, \text{ or } R-\overset{\diagup OH}{\underset{\diagdown R'}{C}}-CN.$$

8. Aldehydes reduce a cold ammoniacal solution of silver nitrate. They also redden a very dilute cold solution of a fuchsine salt which has been decolorized by sulphurous acid. Ketones do not give these reactions.

9. Some aldehydes, especially those of the aromatic series, are converted by caustic potash into an alcohol and a salt of an acid.



$$2\,C_6H_5\overset{\overset{O}{/\!/}}{C}-H + KOH = \underset{\text{Potassium benzoate.}}{C_6H_5CO_2K} + \underset{\text{Benzyl alcohol.}}{C_6H_5CH_2OH.}$$

Many aldehydes, on the other hand, are converted by alkalies into uncrystallizable resins.

Laboratory Exercises.

Preparation of the following substances:

1. Formaldehyde.
2. Acetaldehyde; paraldehyde; metaldehyde; aldehyde ammonia.
3. Ethylidene acetacetic ester. Knoevenagel, *Ann. Chem.* (Liebig), **281**, 104. By a misprint 3.4 g. acetaldehyde is given instead of 34 g.
4. Aldol and crotonic aldehyde.
5. Benzaldehyde.
6. Synbenzaldoxime and antibenzaldoxime.
7. Benzoin and benzil.
8. Acetoxime.
9. Benzalacetone and dibenzalacetone.
10. Propionic and butyric acids from 4-heptanone.
11. Camphoric acid.
12. Acetophenone.
13. Benzophenone.
14. Oxime of benzophenone; Beckmann's re-arrangement.
15. Diacetyl.
16. Acetylacetone.
17. Benzoquinone.
18. Alizarin.

CHAPTER XIII.

ACIDS.

Structure.—In empirical formula all of the common monobasic organic acids differ from the hydrocarbons containing the same number of carbon atoms in that they contain two oxygen atoms in place of two hydrogen atoms. Thus, from methane, CH_4, we have formic acid, CH_2O_2, from ethane we have acetic acid, $C_2H_4O_2$, from toluene, C_7H_8, we have benzoic acid, $C_7H_6O_2$.

Many sodium salts of organic acids, when mixed with soda lime and distilled, give a hydrocarbon containing one carbon atom less than the acid, the change from the acid to the hydrocarbon consisting simply in the loss of carbon dioxide:

$$\underset{\text{Sodium acetate.}}{C_2H_3O_2Na} + NaOH = \underset{\text{Methane.}}{CH_4} + Na_2CO_3$$

Many acids can be prepared from monohalogen derivatives of hydrocarbons by reactions of which the following are typical:

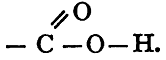
$$\underset{\text{Ethyl bromide.}}{C_2H_5Br} + KCN = \underset{\text{Ethyl cyanide.}}{C_2H_5CN} + KBr$$

$$C_2H_5CN + HCl + 2H_2O = \underset{\text{Propionic acid.}}{C_3H_6O_2} + NH_4Cl$$

A little consideration of these facts leads to the conclusion that organic acids may be considered as substitution products in which the univalent group CO_2H, called *carboxyl*, replaces one hydrogen atom of a hydrocarbon or other carbon compound. According to this view acetic acid is to be written CH_3CO_2H, propionic acid, $C_2H_5CO_2H$, benzoic acid, $C_6H_5CO_2H$.

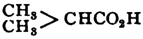
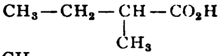
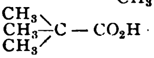
The further structure of the carboxyl group is best shown by the conduct of acids when treated with phosphorus pentachloride.

$$\underset{\text{Acetic acid.}}{CH_3CO_2H} + PCl_5 = \underset{\text{Acetyl chloride.}}{CH_3COCl} + POCl_3 + HCl$$

In almost all cases this treatment results in the exchange of an oxygen and hydrogen atom of the acid for the univalent chlorine atom. This indicates the presence of a hydroxyl group, and gives the structure $-CO.OH$, for the carboxyl group. The relation of the second oxygen atom cannot be well expressed other than thus,  $-\overset{\nearrow O}{C}-O-H$.

Definition of an Acid.—In accordance with the ideas now most generally accepted, an acid is a compound which is dissociated, or ionized in an aqueous solution with the formation of hydrogen ions. From a previous discussion (p. 143) it seems probable that many substances not properly called acids undergo some dissociation of this sort, and that we may have all degrees of ionization, from that of aliphatic alcohols, which dissociate less than water, and whose sodium derivatives are, therefore, decomposed by water, to that of trichloracetic and oxalic acids whose dissociation approaches, or even exceeds, that of some mineral acids. With our present conception of acids it seems to be a little difficult to frame a definition of organic acids or, indeed, of acids in general, which is not more or less arbitrary. Perhaps as satisfactory a definition as we can give is to say that an acid is a substance which ionizes in an aqueous solution so far as to increase the number of hydrogen ions normally present in pure water. Under this definition ethyl alcohol and similar compounds are not acids, although they form such compounds as C_2H_5ONa. Phenol, C_6H_5OH, on the other hand, is an acid, since its aqueous solution contains a sufficient number of hydrogen ions to give it a measurable conductivity (p. 144). While considerations of this sort lead us to include among the organic acids a few compounds which do not contain the carboxyl group, almost all such acids do contain that group.

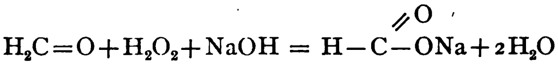
FATTY ACIDS, $C_nH_{2n}O_2$.

		Melting Point.		Boiling Point.
Formic acid	$H-CO_2H$	8.5°		101°
Acetic acid	CH_3CO_2H	16.7°		120°
Propionic acid	$C_2H_5CO_2H$	−23°		140.9°
Butyric acid	$CH_3CH_2CH_2CO_2H$	0°		162.5°
Isobutyric acid	 $\begin{matrix}CH_3\\CH_3\end{matrix}>CHCO_2H$	−79°		153.5°
Valeric acid	$CH_3(CH_2)_3CO_2H$	−18°		186°
Isovaleric acid	 $\begin{matrix}CH_3\\CH_3\end{matrix}>CHCH_2CO_2H$	−51°		176.3°
2-Methylbutanoic acid	 $CH_3-CH_2-\underset{\displaystyle CH_3}{\underset{\vert}{CH}}-CO_2H$	—		177°
Dimethylpropanoic acid	 $\begin{matrix}CH_3\searrow\\CH_3\rightarrow\\CH_3\nearrow\end{matrix}C-CO_2H$	35.5°		163.7°
Caproic acid	$CH_3(CH_2)_4CO_2H$	−1.5°		205°
Isocaproic acid	 $\begin{matrix}CH_3\\CH_3\end{matrix}>CHCH_2CH_2CO_2H$	—		201°
Oenanthylic acid	$CH_3(CH_2)_5CO_2H$	−10.5°		224°
Caprylic acid	$CH_3(CH_2)_6CO_2H$	+16.5°		236°
Pelargonic acid	$CH_3(CH_2)_7CO_2H$	12.5°		253°
Capric acid	$CH_3(CH_2)_8CO_2H$	31°		270°
			At 100 *mm*	200°
Undecylic acid	$CH_3(CH_2)_9CO_2H$	28.5°	"	212.5°
Lauric acid	$CH_3(CH_2)_{10}CO_2H$	43.6°	"	225°
Tridecylic acid	$CH_3(CH_2)_{11}CO_2H$	40.5°	"	236°
Myristic acid	$CH_3(CH_2)_{12}CO_2H$	53.8°	"	250°
Pentadecylic acid	$CH_3(CH_2)_{13}CO_2H$	51°	"	257°
Palmitic acid	$CH_3(CH_2)_{14}CO_2H$	62°	"	271.5°
Margaric acid	$CH_3(CH_2)_{15}CO_2H$	59.8°	"	227°
Stearic acid	$CH_3(CH_2)_{16}CO_2H$	69.2	"	291°
Nondecylic acid	$CH_3(CH_2)_{17}CO_2H$	66.5°	"	298°
Arachidic acid	$CH_3(CH_2)_{18}CO_2H$	75°		—
Behenic acid	$CH_3(CH_2)_{20}CO_2H$	83°		—

Lignoceric acid	$CH_3(CH_2)_{22}CO_2H$	80.5°	—
Hyenic acid	$CH_3(CH_2)_{23}CO_2H$	78°	—
Cerotic acid	$CH_3(CH_2)_{25}CO_2H$ (?)	78°	—
Melissic acid	$CH_3(CH_2)_{28}CO_2H$	90°	—
Dicetyl acetic acid	$\begin{matrix}C_{16}H_{33}\\C_{16}H_{33}\end{matrix}>CHCO_2H$	70°	—

Formic Acid, $H-CO_2H$ **(methanoic acid).**—The first acid of the series is formed:

1. By the oxidation of formaldehyde by means of hydrogen peroxide in alkaline solution:



$$H_2C=O+H_2O_2+NaOH = H-\overset{\displaystyle /\!\!/O}{C}-ONa+2H_2O$$

It need hardly be remarked that the relation between an acid and its salt is so close that the preparation of the salt of an acid is often spoken of as a preparation of the acid.

The oxidation consists, as has been pointed out, in the introduction of an oxygen atom between the carbon and hydrogen atoms. Formic acid may also be formed by the direct oxidation of methyl alcohol.

2. By the action of hydrochloric acid or an alkali on hydrocyanic acid:

$$HCN+HCl+2H_2O = HCO_2H+NH_4Cl$$
$$HCN+KOH+H_2O = HCO_2K + NH_3$$

3. By the absorption of moist carbon monoxide by soda lime at 190°–220°:

$$CO+NaOH=H-CO_2Na$$

Carbon monoxide may be looked upon as the anhydride of formic acid.

4. By the reduction of moist carbon dioxide by metallic potassium, or of ammonium carbonate by sodium amalgam:

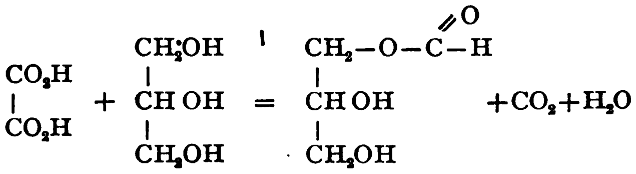
$$2K+2CO_2+H_2O = HCO_2K+HKCO_3$$
$$(NH_4)_2CO_3+2Na = HCO_2Na+2NH_3+NaOH$$

5. By the action of alcoholic potash on chloroform:

$$CHCl_3+4KOH = HCO_2K+3KCl+2H_2O$$

The similarity between this reaction and the formation of aldehydes and ketones from dihalogen derivatives of hydrocarbons should be noticed.

6. Formic acid is practically prepared by heating oxalic acid with glycerol, the decomposition taking place best at a temperature of 115°–125°. The formic acid formed by the decomposition of the oxalic acid reacts at first with the glycerol to form monoformin.



Oxalic acid. Monoformin.

The monoformin then reacts with, or is saponified by the water, giving formic acid, which distills, and regenerating the glycerol:

$$C_3H_5(OH)_2\ (CHO_2) + H_2O = C_3H_5(OH)_3 + H_2CO_2$$

The formic acid obtained in this manner contains water; by fractional distillation it may be concentrated till an acid of 77.5 per cent, boiling at 107.1°, is obtained. A stronger acid can be prepared by dissolving anhydrous oxalic acid in such an acid. On cooling, the oxalic acid crystallizes with water of crystallization leaving formic acid nearly free from water. Another method consists in treating dry lead formate, $(CHO_2)_2Pb$, with hydrogen sulphide.

Pure formic acid solidifies at a low temperature, and melts at 8.5°. It boils at 101°.

Formic acid is a strong acid. From the electrical conductivity, $K = 0.0214$, while for acetic acid $K = 0.00180$ (p. 49).

Formic acid produces painful blisters on the skin. It is secreted by some insects, and is, apparently, the cause of the irritation produced by the sting of the bee. The name is derived from the fact that it was first obtained by the distillation of ants.

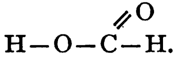
When sodium formate is heated with sodium hydroxide hydrogen is evolved.

$$NaCHO_2 + NaOH = Na_2CO_3 + H_2.$$

When the acid is heated with concentrated sulphuric acid it is decomposed with evolution of carbon monoxide.

$$CH_2O_2 = CO + H_2O.$$

Formates of many of the metals are known. The lead and copper salts crystallize well, and are used for the purpose of purification.

From its structure formic acid may be considered in some sense as an aldehyde,  $H-O-\overset{\overset{\large O}{/\!/}}{C}-H$. In accordance with this structure it is a strong reducing agent, an ammoniacal solution of silver nitrate being reduced by it to metallic silver, and mercuric chloride being reduced to mercurous chloride and then to metallic mercury. These reactions are used for its qualitative detection.

Acetic Acid, CH_3CO_2H **(ethanoic acid).**—Acetic acid is practically prepared by the oxidation of alcohol, or by the destructive distillation of wood. The impure acid obtained in the second manner is sometimes called pyroligneous acid.

The oxidation of alcohol, while it can be effected by means of chromic acid and other oxidizing agents, is practically carried out by a process of fermentation. The microorganism known as *Bacterium aceti*, or "mother of vinegar," is the effective agent; but, unlike the alcoholic fermentation, oxygen must also be present. In the slow vinegar process, cider, wine, or a dilute alcohol resulting from the fermentation of a malt liquor, is allowed to stand for some weeks in casks which are sufficiently open to allow a very slow circulation of air.

In the "quick vinegar process" dilute alcohol of 6 to 10 per cent is allowed to trickle slowly over beech shavings which have been previously inoculated with the living ferment. A slow current of air through the apparatus used is secured by suitable openings and by the fact that the reaction is accompanied by an evolution of heat. The temperature must be regulated, 35° being most suitable.

The acetic acid prepared as described is mostly used as vinegar. A stronger acetic acid is obtained usually from the mixture of substances formed by the destructive distillation of wood. Oak, beech, and similar woods of comparatively young growth (trees 3 to 4 inches in diameter) are most suitable for the purpose; and, to obtain an acid which can be readily purified, only a moderate temperature (190°–205°) should be employed.

By fractional distillation a dilute acetic acid can be concentrated, and an acid nearly free from water can finally be obtained. Practically, however, a dilute acid is converted into its calcium or sodium salt, the water is evaporated, and the dry salt is decomposed with hydrochloric or sulphuric acid.

Pure acetic acid melts at 16.7°, and boils at 120°. It has a specific gravity of 1.055 at 15°. The addition of water *increases* the specific gravity to a maximum of 1.075 for an acid of 80 per cent. This corresponds approximately to $C_2H_4O_2 + H_2O$, and may be due to the formation of the compound $CH_3–C(OH)_3$. Further addition of water causes the specific gravity to decrease again. An acid of about 43 per cent has the same specific gravity as the pure acid, and between these limits each specific gravity corresponds to acids of two degrees of concentration. In a given case, whether a strong or weak acid is in hand, can be determined by adding a little water and noting whether the specific gravity increases or decreases.

Salts of Acetic Acid. — Many *acetates* are known, the most interesting being lead acetate, $Pb(C_2H_3O_2)_2 + 3H_2O$, or sugar of lead; a basic lead acetate, $Pb(OH)C_2H_3O_2$, or $PbO + Pb(C_2H_3O_2)_2 + H_2O$, formed by dissolving litharge in a solution of lead acetate, and much used to clarify sugar solutions; calcium acetate, $Ca(C_2H_3O_2)_2 + H_2O$; and sodium acetate, $NaC_2H_3O_2 + 3H_2O$.

Acid Salts of Acetic Acid. — Sodium and potassium also form with acetic acid, acid salts, as $KH(C_2H_3O_2)_2$ and $KH_2(C_2H_3O_2)_3$. Whether the acetic acid of such salts is to be looked upon as similar to water of crystallization, or whether the salt is to be considered as derived from a polymer of acetic acid, is, at present, only a matter for speculation. It may, indeed, be questioned whether there is any real difference between the two views. It is interesting to notice, in this connection, that at temperatures slightly above its boiling point the vapor density of acetic acid is abnormally high, indicating the presence in the vapor of molecular aggregations or of a polymeric form.

Decompositions. — By heating sodium acetate with soda-lime methane is formed, and by the electrolysis of acetic acid ethane and carbon dioxide are evolved at the anode, and hydrogen at the kathode. The significance of these reactions in their relation to the structure of acetic acid has been discussed.

Uses. — Dilute acetic acid is used chiefly in the form of vinegar. Since there is no tax upon it, it is used to a limited extent in place of alcohol for the preparation of fluid extracts of some drugs, especially those containing alkaloids. The aluminium, iron, and chromium salts are used as mordants in dyeing and calico printing. Acetic acid and iron are used for the reduction of nitro compounds in the manufacture of artificial colors.

Propionic Acid, $CH_3CH_2CO_2H$ (**propanoic acid**), can be obtained by the oxidation of normal propyl alcohol, $CH_3CH_2CH_2OH$. It may also be prepared from ethyl cyanide. When ethyl alcohol is mixed with concentrated sulphuric acid it is partly converted into ethyl sulphuric acid, $C_2H_5HSO_4$. On diluting and neutralizing with calcium carbonate the calcium salt of this acid remains in solution, while most of the sulphuric acid is deposited as insoluble calcium sulphate. By precipitating the filtrate exactly with sodium or potassium carbonate the sodium or potassium salt is formed, and may be obtained dry by evaporating the faintly alkaline solution, an acid solution being relatively unstable and decomposing with the formation of acid potassium sulphate and alcohol. When the dry potassium salt is mixed with potassium cyanide and distilled, ethyl cyanide is formed.

$$KC_2H_5SO_4 + KCN = K_2SO_4 + C_2H_5CN.$$

Ethyl cyanide may also be prepared by dissolving potassium cyanide in its own weight of water, adding the calculated amount of ethyl bromide diluted with three or four parts of alcohol, and boiling with an upright condenser for some time.

$$C_2H_5Br + KCN = C_2H_5CN + KBr.$$

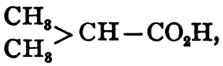
From ethyl cyanide the propionic acid can be obtained by "saponification" with an acid or an alkali.

$$2C_2H_5CN + H_2SO_4 + 4H_2O = 2C_2H_5CO_2H + (NH_4)_2SO_4$$
$$C_2H_5CN + KOH + H_2O = C_2H_5CO_2K + NH_3.$$

These reactions are general in their application. Since halogen derivatives of the hydrocarbons are readily prepared from primary alcohols, and since the chlorides of acids can be reduced to aldehydes and primary alcohols, it is possible to start with methyl alcohol and prepare from it, synthetically, the whole series of normal fatty acids.

Normal Butyric Acid, or **Butanoic Acid,** $CH_3CH_2CH_2CO_2H$, is found in comparatively small amount in butter in the form of its glycerol ester, $C_3H_5(C_4H_7O_2)_3$. Butyric acid is practically prepared by the fermentation of glucose, in the presence of calcium carbonate, and under the influence of a ferment which is found in old Limburger cheese.

Isobutyric Acid, or **Methylpropanoic Acid,**



$$\begin{matrix}CH_3\\CH_3\end{matrix}\!\!>CH-CO_2H,$$

is obtained by the oxidation of the isobutyl alcohol, isolated from fusel oil, or by the saponification of isopropyl cyanide, which can be prepared from isopropyl iodide, CH_3CHICH_3.

The calcium salt of normal butyric acid is less soluble in hot than in cold water. A cold, saturated solution of the salt gives, therefore, a precipitate on warming. The cold saturated solution of calcium isobutyrate, on the contrary, gives no such precipitate.

Acids, $C_5H_{10}O_2$. — Four acids of the formula, $C_5H_{10}O_2$, are known. The most important is the ordinary valeric acid, or more correctly *isovaleric acid* (methyl-3-butanoic acid),  $\begin{matrix}CH_3\\CH_3\end{matrix}{>}CHCH_2CO_2H$. This is found in valerian root, and is also prepared by the oxidation of the isoamyl alcohol of fusel oil. (How could it be prepared from isobutyl alcohol?)

Palmitic Acid, $C_{16}H_{32}O_2$, and Stearic Acid, $C_{18}H_{36}O_2$, are found in the form of their glycerol esters, *palmitin*, $C_3H_5(C_{16}H_{31}O_2)_3$, and *stearin*, $C_3H_5(C_{18}H_{35}O_2)_3$, in many of the natural fats. Palmitin is found especially in palm-oil, in Japanese vegetable wax, Chinese tallow, and cocoanut-oil. Stearin is found in tallow, in shea-butter from West Africa, and in many other fats.

Soaps. — When fats are treated with sodium hydroxide, or sodium carbonate, they are saponified, and sodium salts of the fatty acids are formed. These sodium salts are the ordinary *soaps*.

$$\underset{\text{Palmitin.}}{C_3H_5(C_{16}H_{31}O_2)_3} + 3NaOH = \underset{\text{Sodium palmitate.}}{3C_{16}H_{31}O_2Na} + \underset{\text{Glycerol.}}{C_3H_5(OH)_3}.$$

The sodium and potassium salts of the higher fatty acids are easily soluble in water, but the calcium and magnesium salts are insoluble. With a "hard" water, therefore, soap will not produce a "lather" till enough has been used to precipitate all of the calcium and magnesium present.

The soaps are, apparently, partly decomposed in dilute solutions with liberation of free alkali, which then attacks grease and removes it. Since, however, soaps will aid in the removal of paraffin oils which are not attacked by alkali, it seems evident that the soap attacks or dissolves oily substances directly in such a manner that they will subsequently form an emulsion with the water, and can then be washed away.

Structure of the Natural Fatty Acids. — Krafft has proved that the natural fatty acids from caprylic acid to arachidic acid have the normal structure. By distilling a mixture of barium stearate and barium acetate the ketone $C_{17}H_{35}COCH_3$ was obtained.

$$(C_{17}H_{35}CO_2)_2Ba + (C_2H_3O_2)_2Ba = 2C_{17}H_{35}COCH_3 + 2BaCO_3.$$

This ketone, by oxidation, gave margaric acid, $C_{16}H_{33}CO_2H$. Stearic acid must therefore have the structure

$$C_{16}H_{33}CH_2CO_2H.$$

The same process was repeated till capric acid,

$$C_9H_{19}CO_2H,$$

was reached. Since capric acid has been prepared from normal octyl iodide,

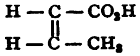
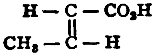
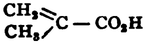
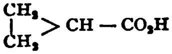
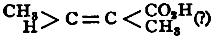
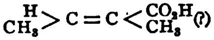
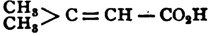
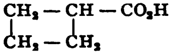
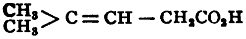
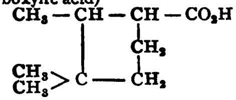
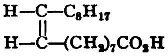
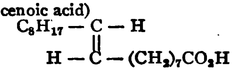
$$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2I,$$

by the acetacetic ester synthesis (p. 350) the normal structure of stearic acid and of the intermediate acids is demonstrated. By reducing the chloride of stearic acid, $C_{17}H_{35}COCl$, the aldehyde, $C_{17}H_{33}COH$, and the alcohol, $C_{17}H_{35}CH_2OH$, and from the last the iodide, $C_{17}H_{35}CH_2I$, were prepared. From this, by the acetacetic ester synthesis, again, arachidic acid was obtained. This must have, therefore, the structure

$$C_{17}H_{35}CH_2CH_2CO_2H,$$

and, since stearic acid has been shown to have the normal structure by the work described above, the proof is complete.

ACIDS $C_nH_{2n-2}O_2$.

		Melting Point.	Boiling Point.
Acrylic acid	$CH_2=CH-CO_2H$	8°	140°
Crotonic acid (Δ¹-Cisbutenoic acid)	 $\begin{matrix}H-C-CO_2H\\ \Vert\\ H-C-CH_3\end{matrix}$	72°	185°
Isocrotonic acid (Δ¹ Transbutenoic acid)	 $\begin{matrix}H-C-CO_2H\\ \Vert\\ CH_3-C-H\end{matrix}$	15.5°	172°
Methacrylic acid (Methyl propenoic acid)	 $^{CH_2}_{CH_3}\!\!>C-CO_2H$	16°	160.5°
Cyclopropane carboxylic acid	 $^{CH_2}_{CH_2}\!\!>CH-CO_2H$	19°	181°–184°
Allylacetic acid (Δ³ Pentenoic acid)	$CH_2=CH-CH_2CH_2CO_2H$	fluid	187°–189°
Ethylidene propionic acid (Δ²-Pentenoic acid)	$CH_3-CH=CH-CH_2CO_2H$	fluid	193°–194°
Propylidene acetic acid (Δ¹-Pentenoic acid)	$CH_3CH_2-CH=CHCO_2H$	fluid	194°–195°
Angelic acid	 $^{CH_3}_{H}\!\!>C=C<^{CO_2H}_{CH_3}$ (?)	45°	185°
Tiglic acid	 $^{H}_{CH_3}\!\!>C=C<^{CO_2H}_{CH_3}$ (?)	64.5°	198.5°
Dimethyl acrylic acid (Δ¹ Methyl-3-butenoic [*] acid)	 $^{CH_3}_{CH_3}\!\!>C=CH-CO_2H$	70°	195°
Cyclobutane carboxylic acid	 $\begin{matrix}CH_2-CH-CO_2H\\ \vert\quad\;\vert\\ CH_2-CH_2\end{matrix}$	fluid	192°
Hydrosorbic acid (Δ³ Hexenoic acid)	$CH_3-CH_2-CH=CH-CH_2CO_2H$	fluid	208°
Pyroterebic acid	 $^{CH_3}_{CH_3}\!\!>C=CH-CH_2CO_2H$	6°	207°
Dihydro-β-Campholytic acid (Dihydroisolauronolic acid) (2-3,3 Trimethylcyclopentane carboxylic acid)	 $\begin{matrix}CH_3-CH-CH-CO_2H\\ \vert\qquad\vert\\ \qquad CH_2\\ \vert\qquad\vert\\ ^{CH_3}_{CH_3}\!\!>C-CH_2\end{matrix}$	fluid	244°
Oleic acid (Δ⁸ Cis (or trans) octadecenoic acid)	 $\begin{matrix}H-C-C_8H_{17}\\ \Vert\\ H-C-(CH_2)_7CO_2H\end{matrix}$	14°	At 100 mm. 286°
Elaïdic acid (Δ⁸ Trans (or cis) octadecenoic acid)	 $\begin{matrix}C_8H_{17}-C-H\\ \Vert\\ H-C-(CH_2)_7CO_2H\end{matrix}$	45°	288°

Very many other acids of this group are known.

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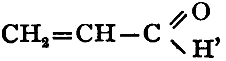
[*] The apparent inconsistency of this name is due to the fact that, in defining double unions the carbon atom adjacent to the carboxyl is numbered 1, while in the official nomenclature the end carbon atom is 1.

Acrylic Acid, $CH_2 = CHCO_2H$ **(propenoic acid),** may be prepared by treating β-iodo-propionic* acid, $CH_2ICH_2CO_2H$, with alcoholic potash; by heating salts of either lactic acid, $CH_3CHOHCO_2H$, or hydracrylic acid, $CH_2OH\text{–}CH_2CO_2H$; by careful oxidation of acroleïn,  $CH_2{=}CH{-}C\begin{matrix}{/\!\!/}O\\ \diagdown H\end{matrix}$, with silver oxide; and by oxidation of 2,3-dibrompropanol-1,

$$CH_2BrCHBrCH_2OH,$$

with nitric acid, followed by the reduction of the resulting dibrompropionic acid,

$$CH_2BrCHBrCO_2H,$$

with zinc and sulphuric acid. It is to be noticed that reduction in this case merely removes bromine, and does not replace it with hydrogen. This sort of action of reducing agents upon compounds in which two bromine atoms are combined with adjacent carbon atoms is very common.

The similarity between the first methods given for the preparation of acrylic acid and the methods used for the preparation of hydrocarbons of the ethylene series is significant. The fact that similar reactions may often be applied to compounds of very diverse character is of great practical importance in organic chemistry. It should be remembered, however, that while the reasoning from analogy based on this fact is often an indispensable guide, it is frequently unreliable when used to determine the structure of compounds. *Often reliable conclusions can be reached only after the accumulation of a large mass of evidence, and a single line of reasoning, which might seem satisfactory in a text-book, is, at times, very delusive in actual work.*

The chemical properties of acrylic acid are largely indi-

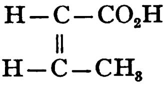
---

* Derivatives of acids are named by designating the carbon atoms by the Greek letters α, β, γ, Δ, ε, ζ . . . ω, beginning with the carbon atom adjacent to the carboxyl.

cated by its structure. It shows all of the ordinary reactions of organic acids, so far as these are not interfered with by the presence of the very reactive double union; and it gives the reactions characteristic of unsaturated bodies. It takes up two chlorine or bromine atoms directly, giving α-β-dichlor- or α-β-dibrompropionic acid, $CH_2BrCHBrCO_2H$. It adds hydrochloric, hydrobromic, or hydriodic acid, the halogen taking the β-position in accordance with the "positive-negative" law (p. 191), giving, for example, β-iodopropionic acid, $CH_2ICH_2CO_2H$. Nascent hydrogen converts this into propionic acid. Fusion with caustic potash gives formic acid and acetic acids:

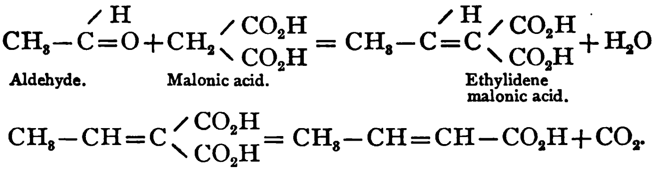
$$CH_2=CHCO_2H+2KOH = H-CO_2K+CH_3CO_2K+H_2.$$

Crotonic Acid (**Δ**^{1} **Cisbutenoic acid**),



$$\begin{matrix} H-C-CO_2H \\ \| \\ H-C-CH_3 \end{matrix}$$

. Ordinary crotonic acid is found in croton oil, and is prepared by heating α-brombutyric acid, $CH_3CH_2CHBrCO_2H$, or β-iodobutyric acid with caustic potash. It is also formed by heating paraldehyde with malonic and acetic acids.



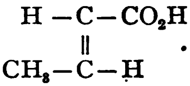
$$CH_3-\overset{/H}{C}=O+CH_2\begin{matrix}/CO_2H\\ \backslash CO_2H\end{matrix} = CH_3-\overset{/H}{C}=C\begin{matrix}/CO_2H\\ \backslash CO_2H\end{matrix}+H_2O$$

Aldehyde. Malonic acid. Ethylidene malonic acid.

$$CH_3-CH=C\begin{matrix}/CO_2H\\ \backslash CO_2H\end{matrix}= CH_3-CH=CH-CO_2H+CO_2.$$

The structure of crotonic acid follows from the method of preparation, and from the fact that the β-iodobutyric acid, formed by adding hydriodic acid to it, is reduced, by sodium amalgam, to normal butyric acid.

Isocrotonic Acid (Δ^1 **Transbutenoic acid**),



$$\begin{matrix} H-C-CO_2H \\ \| \\ CH_3-C-H \end{matrix}.$$

When acetacetic ester is treated with phosphorus pentachloride it is converted into the chlorides of two isomeric chlorcrotonic acids.

$$
\begin{aligned}
&\mathrm{CH_3C(OH) = CH - CO_2C_2H_5 + 2PCl_5}\\
&\qquad\mathrm{= CH_3 - CCl = CH - COCl + HCl + 2POCl_3 + C_2H_5Cl,}\\
&\text{or }\mathrm{CH_3CO - CH_2 - CO_2C_2H_5 + 2PCl_5}\\
&\qquad\qquad\mathrm{= 2POCl_3 + C_2H_5Cl + CH_3CCl_2 - CH_2COCl,}\\
&\qquad\qquad\mathrm{= CH_3 - CCl = CH - COCl + HCl.}
\end{aligned}
$$

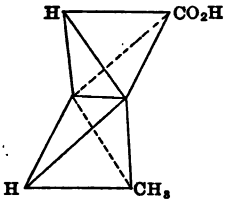
On treatment with water, these chlorides are converted into two chlorcrotonic acids, one of which melts at 94°, and is called β-chlorcrotonic acid, while the other melts at 59°, and is called β-chlorisocrotonic acid.

$$
\begin{aligned}
&\mathrm{CH_3 - CCl = CH - COCl + H_2O}\\
&\qquad\qquad\qquad = \underset{\substack{\beta\text{-Chlorcrotonic acid,}\\ \text{or } \beta\text{-Chlorisocrotonic acid.}}}{\mathrm{CH_3 - CCl = CH - CO_2H}} \mathrm{+ HCl}
\end{aligned}
$$

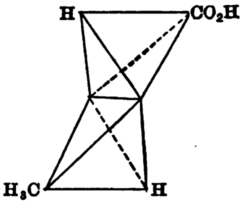
One of the acids is easily volatile with water vapor, while the other is not, and they may be separated by this means.

The first of these acids gives, by reduction, crotonic acid; the second gives isocrotonic acid. In the earlier discussion of the structure of the crotonic acids, it was thought that ordinary crotonic acid has the structure $\mathrm{CH_3 - CH = CH - CO_2H}$, and isocrotonic acid that represented by the formula $\mathrm{CH_2 = CH - CH_2 - CO_2H}$. The further development of organic chemistry has led, however, to the discovery that very many compounds containing a double union exist in two forms which are evidently dependent on the mere presence of the double union and not on the position of that union. This peculiar form of isomerism has been called by Michael (*Ber. d. chem. Ges.* 19, 1384) *alloisomerism*, and the more stable of the two given forms is distinguished by the prefix "allo." In the present case the ordinary crotonic acid would be called allocrotonic acid, since isocrotonic acid is converted into it by heating. Michael attempts no explanation of the cause of this kind of isomerism.

Stereoisomerism. — On the basis of his conception of the arrangement in space (p. 137) of the atoms of carbon compounds, Van't Hoff has proposed a theory with regard to the sort of isomerism under consideration. In single unions between carbon atoms it is assumed that each atom is free to rotate around the point of union. When, however, a double union is formed, this free rotation is supposed to be no longer possible. On this supposition the crotonic acids may exist in two forms, which will be apparent from the following figures



Crotonic acid "Cis" form, plane symmetric configuration.



Isocrotonic acid "Trans" form, central or axially symmetric configuration.

The prefixes "cis," meaning "on this side," and "trans," meaning "across," have been proposed to distinguish the two forms.

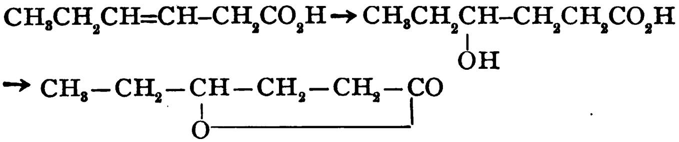
The assignment of the true configuration to the isomers, is not always possible. In the present case, ordinary crotonic acid is supposed to have the "cis" form because it is produced by the reduction of tetrolic acid, $CH_3-C\equiv C-CO_2H$. The significance of this will be apparent from the figures of the crotonic acids. Only the first form could readily result by the addition of hydrogen to tetrolic acid.

The best evidence that the two crotonic acids are stereomeric bodies, and not "place isomers,"* lies in the fact that each gives with hydriodic acid the same *β*-iodobutyric acid, $CH_3CHICH_2CO_2H$.

Stereoisomers, as a rule, readily pass from one form into the other, and bodies containing double unions often undergo other rearrangements. For these reasons evidence with regard to the relations between such compounds is often conflicting, and even more than the usual caution against dogmatic conclusions is required.

Hydrosorbic Acid (**Δ^2 Hexenoic acid**), $CH_3CH_2-CH=CH-CH_2CO_2H$, is prepared by the reduction of *sorbic acid*, $CH_3CH=CH-CH=CH-CO_2H$, with sodium amalgam. The apparent shifting of a double union during the reduction has been found to be general for many similar cases. Apparently the hydrogen adds itself to the *α*- and *δ*-carbon atoms, while the valences of the *β*- and *γ*-carbon atoms, momentarily free, result in a union between those atoms. (Baeyer, *Ann. d. Chem.* (Liebig), 251, 279; Thiele, *Ibid*, 306, 87; Erlenmeyer Jr., *Ibid*, 316, 43.)

When hydrosorbic acid is boiled for a moment with sulphuric acid which has been diluted with an equal volume of water, it is converted into caprolactone. Water is, apparently, added and split off again thus:—



$$CH_3CH_2CH{=}CH{-}CH_2CO_2H \rightarrow CH_3CH_2\underset{\displaystyle OH}{\underset{|}{CH}}{-}CH_2CH_2CO_2H$$

$$\rightarrow CH_3-CH_2-\underbrace{CH-CH_2-CH_2-CO}_{O}$$

Caprolactone.

This reaction is characteristic of almost all *β*-*γ*-unsaturated acids. The same transformation is also effected by strong hydrobromic acid or, in many cases, by merely boiling

---

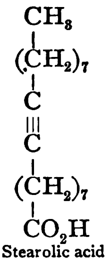
* That is, isomers in which the positions of the double unions and of the hydrogen atoms differ.

the acids. (Fittig, *Ber. d. chem. Ges.* **27**, 2667; *Ann. d. Chem.* (Liebig), **283**, 51.)

When hydrosorbic acid is boiled with a strong solution of sodium hydroxide it is changed to Δ^1*hexenoic acid*, CH_3CH_2-$CH_2CH{=}CHCO_2H$. This transformation is also supposed to be due to the addition, and subsequent loss of water, and is characteristic of many β-γ-unsaturated acids. (Baeyer; *Ann. d. Chem.* (Liebig), **251**, 268; Fittig, *Ann. d. Chem.* (Liebig), **283**, 50.)

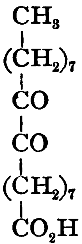
For the conduct of the halogen addition products of such acids, see p. 395.

Oleïc Acid, $C_8H_{17}CH = CH(CH_2)_7CO_2H$, is found in the form of its glyceride *oleïn* in olive-oil, lard and other fats. Nitrous acid converts oleïc acid into *elaïdic acid.* Since hydriodic acid reduces both oleïc acid and elaïdic acid to stearic acid, $CH_3(CH_2)_{16}\,CO_2H$, each must contain a normal chain of carbon atoms. Since the dibromide of each acid gives with alcoholic potash, *stearolic* acid, $C_{18}H_{32}O_2$, it seems probable that the double union is in the same position in each and that the acids are stereomeric. Stearolic acid is converted, by oxidation with nitric acid, into *stearoxylic* acid, $C_{18}H_{32}O_4$, and the latter, by further oxidation, into a mixture of *pelargonic acid*, $C_9H_{18}O_2$, and *azelaic acid*, $(CH_2)_7(CO_2H)_2$. These reactions establish the structure:—



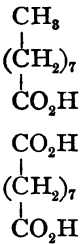
$$\begin{array}{c} CH_3 \\ | \\ (CH_2)_7 \\ | \\ C \\ ||| \\ C \\ | \\ (CH_2)_7 \\ | \\ CO_2H \end{array}$$

Stearolic acid.



$$\begin{array}{c} CH_3 \\ | \\ (CH_2)_7 \\ | \\ CO \\ | \\ CO \\ | \\ (CH_2)_7 \\ | \\ CO_2H \end{array}$$

Stearoxylic acid



$$\begin{array}{c} CH_3 \\ | \\ (CH_2)_7 \\ | \\ CO_2H \\ \\ CO_2H \\ | \\ (CH_2)_7 \\ | \\ CO_2H \end{array}$$

Pelargonic and azelaic acids.

By careful oxidation with potassium permanganate, oleïc acid is converted into *dioxystearic acid*,

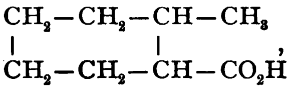
$$CH_3(CH_2)_7CHOHCHOH(CH_2)_7CO_2H.$$

This reaction, again, is characteristic of unsaturated acids. (See also pp. 153 and 162.)

By fusion with caustic potash oleïc acid gives palmitic and acetic acids. An erroneous structure was formerly ascribed to the acid on the basis of this fact.

The properties of the cyclic acids of the formula $C_nH_{2n-2}O_2$, so far as they are peculiar, follow in general from the properties of the cyclic hydrocarbons. They are to be considered as saturated compounds, and as such resemble the saturated fatty acids. A cold solution of an unsaturated acid in sodium carbonate gives, with potassium permanganate, an immediate brown coloration or precipitate. Cyclic acids with the same treatment retain for a longer or shorter time the red color of the potassium permanganate. This means of diagnosis has proved to be of very great service in practical work.

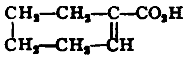
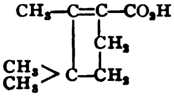
Stereoisomerism of Cyclic Compounds. — When a cyclic compound contains two groups or atoms combined with different carbon atoms a "cis" and "trans" stereoisomerism is possible. Thus, *hexahydroorthotoluic acid* (1 *methyl cyclohexane-2-carboxylic acid*),



$$\begin{array}{ccccccc} CH_2 & - & CH_2 & - & CH & - & CH_3 \\ | & & & & | & & \\ CH_2 & - & CH_2 & - & CH & - & CO_2H \end{array}$$

, exists in two forms. In one of these ("cis") the methyl and carboxyl are supposed to be on the same side of the plane of the ring; in the other form ("trans" or "cis trans") they are supposed to be on opposite sides of that plane. The relation is most clearly apparent by use of a model. Isomerism of this kind has been observed in very many cases.

ACIDS, $C_nH_{2n-4}O_2$.

		Melting Point.	Boiling Point.
Propiolic acid (Propinoic acid)	$CH{\equiv}C{-}CO_2H$	6°	92° at 50 mm.
Tetrolic acid	$CH_3{-}C{\equiv}C{-}CO_2H$	76°	203°
Sorbic acid ($\Delta^{1,3}$ Hexenoic acid)	$CH_3{-}CH{=}CH{-}CH{=}CH{-}CO_2H$	134.5°	228°
Δ^1-Tetrahydrobenzoic acid (Δ^1-Cyclohexenoic acid)		29°	240°–243°
β-Campholytic acid (Isolauronolic acid) $\Delta^{1\text{-}2,33}$ Trimethyl cyclopentenoic acid		133°	256°

Many other acids of this general formula are known.

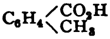
Four classes of acids having the formula $C_nH_{2n-4}O_2$ are possible.

1. Acids having one triple union (or acetylene union).
2. Acids having two double unions (or ethylene unions).
3. Cyclic acids having one double union.
4. Bicyclic acids.

Acids of each class except the last are represented in the table. *Tetrolic acid* (p. 236) and *sorbic acid* (p. 237) have already been referred to. The other acids of the group do not require especial mention.

The principles which underlie the formation of acids in groups which contain still less hydrogen are sufficiently apparent from those which have been considered. Of these groups, that containing the "aromatic" acids is of greatest importance.

AROMATIC ACIDS, $C_nH_{2n-8}O$.

			Melting Point.	Boiling Point.
Benzoic acid		$C_6H_5CO_2H$	121.4°	249°
o-Toluic	" (1.2)	 $C_6H_4\begin{matrix}\diagup CO_2H \\ \diagdown CH_3\end{matrix}$	102°	259°
m- "	" (1.3)	"	110.5°	263°
p- "	" (1.4)	"	180°	274°

α-Toluic acid Phenyl acetic acid	$C_6H_5CH_2CO_2H$	76.5°	265.5°
Hemellithic acid	$C_6H_3\begin{matrix}CH_3 & 1.\\ CH_3 & 2.\\ CO_2H & 3.\end{matrix}$	144°	——
Paraxylic acid	$C_6H_3\begin{matrix}CH_3 & 1.\\ CH_3 & 2.\\ CO_2H & 4.\end{matrix}$	163°	——
Neighboring xylic acid	$C_6H_3\begin{matrix}CH_3 & 1.\\ CO_2H & 2.\\ CH_3 & 3.\end{matrix}$	116°	274.5°
Xylic acid	$C_6H_3\begin{matrix}CH_3 & 1.\\ CH_3 & 3.\\ CO_2H & 4.\end{matrix}$	126°	267°
Mesitylenic acid	$C_6H_3\begin{matrix}CH_3 & 1.\\ CH_3 & 3.\\ CO_2H & 5.\end{matrix}$	166°	——
Isoxylic acid	$C_6H_3\begin{matrix}CH_3 & 1.\\ CO_2H & 2.\\ CH_3 & 4.\end{matrix}$	132°	268°
Hydrocinnamic acid	$C_6H_5CH_2CH_2CO_2H$	48.7°	279.8°
Cuminic acid	$C_6H_4\begin{matrix}CO_2H & 1.\\ CH\begin{matrix}CH_3\\ CH_3\end{matrix} & 4.\end{matrix}$	116°	——
Cinnamic acid	$C_6H_5CH{=}CH{-}CO_2H$	133°	300°

Very many other acids of this group and of groups containing less hydrogen are known, but only a few of these need be mentioned.

Benzoic Acid, $C_6H_5CO_2H$, was originally obtained from gum benzoin by sublimation, or by treatment with alkalies. It is also prepared:

1. By the oxidation of benzyl alcohol, $C_6H_5CH_2OH$, benzaldehyde, C_6H_5CHO, toluene, $C_6H_5CH_3$, benzyl chloride, $C_6H_5CH_2Cl$, ethyl benzene, $C_6H_5C_2H_5$, or practically of any derivative of benzene containing but a single side chain and in which the atom attached to the nucleus is carbon.

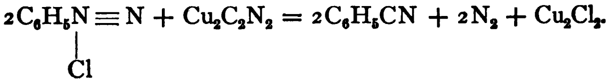
2. By the saponification of phenyl cyanide.

$$2\,C_6H_5CN + H_2SO_4 + 4\,H_2O = 2\,C_6H_5CO_2H + (NH_4)_2SO_4.$$

The phenyl cyanide is prepared:

a. By distilling a mixture of potassium cyanide with chlorbenzene, C_6H_5Cl, brombenzene, C_6H_5Br, or potassium benzene sulphonate, $C_6H_5SO_3K$.

b. By the action of cuprous cyanide on benzene diazonium chloride (p. 461):

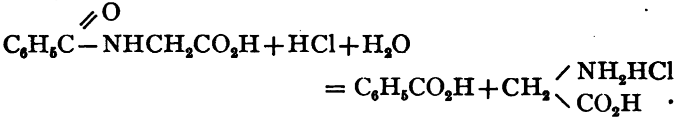


$$2C_6H_5\underset{\displaystyle\overset{|}{Cl}}{N}\equiv N + Cu_2C_2N_2 = 2C_6H_5CN + 2N_2 + Cu_2Cl_2.$$

3. By heating benzotrichloride, $C_6H_5CCl_3$, with water or alkalies.

4. By the action of carbon dioxide and aluminium chloride on benzene.

5. By the decomposition of hippuric acid by hydrochloric acid:



$$C_6H_5\overset{\displaystyle O}{\overset{/\!/}{C}}-NHCH_2CO_2H+HCl+H_2O$$
$$= C_6H_5CO_2H+CH_2\begin{cases} NH_2HCl \\ CO_2H \end{cases}.$$

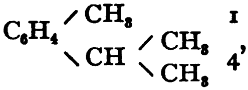
Chloride of glycocoll
or aminoacetic acid.

Benzoic acid crystallizes in needles. It is difficultly soluble in cold water, more easily soluble in hot water, very readily soluble in alcohol and ether. It sublimes easily, and is quite readily volatile with steam. The vapors produce coughing.

Oxidation of Derivatives of Benzene. — The oxidation of derivatives of benzene not only furnishes a means of preparing many acids of the aromatic series, but it also serves as a means of determining the structure of many compounds. Thus, if the oxidation of a compound gives benzoic acid, it is evident that the original compound had but one side chain. If the oxidation yields a phthalic acid, $C_6H_4\begin{cases} CO_2H \\ CO_2H \end{cases}$, not only must the compound oxidized have had two side chains, but, according as phthalic acid (ortho), isophthalic acid (meta) or terephthalic acid is obtained, must the position of the original groups have been ortho, meta, or para.

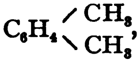
The most common oxidizing agents are chromic acid, dilute nitric acid, potassium permanganate, and potassium ferricyanide.

Chromic Acid (or, usually, potassium pyrochromate and sulphuric acid) oxidizes readily side chains which have no other group in the ortho position. Thus, cymene,



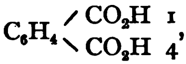
$$C_6H_4\begin{cases} CH_3 & 1 \\ CH\begin{cases} CH_3 \\ CH_3 \end{cases} & 4 \end{cases},$$

or paraxylene,



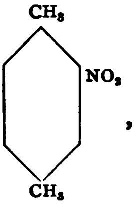
$$C_6H_4\begin{cases} CH_3 \\ CH_3 \end{cases},$$

are readily oxidized to terephthalic acid,

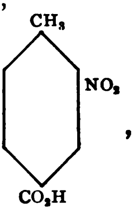


$$C_6H_4\begin{cases} CO_2H & 1 \\ CO_2H & 4 \end{cases},$$

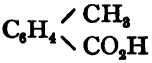
by chromic acid, but nitroparaxylene,



gives only nitrotoluic acid,

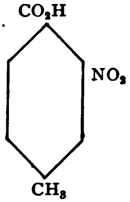


with the same agent.

Nitric Acid acts very much as chromic acid does, but less vigorously, so that intermediate oxidation products are more easily obtained by means of it than by means of chromic acid. Thus, cymene gives with nitric acid paratoluic acid,  $C_6H_4<^{CH_3}_{CO_2H}$. The presence of an ortho group interferes with oxidation by nitric acid, as in the case of chromic acid, but there are a few cases where such groups have been oxidized by this agent.

Potassium Permanganate is used in alkaline solutions. Ortho groups may be oxidized by it, and no selective action has been established.

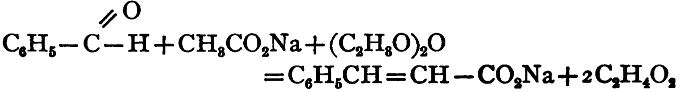
Potassium Ferricyanide is also used in alkaline solutions. In nitro compounds, a methyl group in the ortho or para position is much more easily oxidized than one in the meta position. Thus, nitroparaxylene gives the nitrotoluic acid,



, with this agent.

Cinnamic Acid, $C_6H_5CH=CH-CO_2H$, is found in liquid storax and in a number of other natural products. It is prepared:

1. By heating together benzaldehyde, sodium acetate and acetic anhydride (Perkin's synthesis):

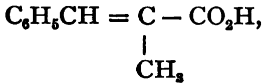


$$C_6H_5-\overset{\displaystyle /\!\!/O}{C}-H+CH_3CO_2Na+(C_2H_3O)_2O$$
$$=C_6H_5CH=CH-CO_2Na+2C_2H_4O_2$$

This reaction, which is both historically and practically a very important one, was made the subject of careful investigation by a number of different chemists, and the following facts about it were gradually established.

a. The condensation is with the sodium salt and not with the acetic anhydride.

b. The condensation occurs with the carbon atom adjacent to the carboxyl in the case of homologues of acetic acid. Sodium propionate, $CH_3CH_2CO_2H$, gives *a-methyl cinnamic acid*,

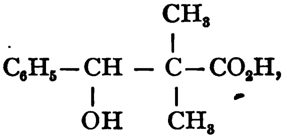


$$\begin{array}{l} C_6H_5CH = \underset{\displaystyle CH_3}{\underset{|}{C}} - CO_2H, \end{array}$$

and *not phenyl vinyl acetic acid*,

$$C_6H_5CH{=}CH-CH_2CO_2H.$$

c. The condensation is at first an addition, giving a hydroxy acid, followed by a loss of water. This is proved by the fact that when the carbon atom adjacent to the carboxyl bears but one hydrogen atom, the hydroxy acid formed may be isolated. Thus, with sodium isobutyrate, $\begin{matrix} CH_3 \\ CH_3 \end{matrix} > CHCO_2Na$, and isobutyric anhydride, oxypivalinic acid, (*a-a*-dimethyl-β-phenyl-β-hydroxy-propionic acid),



$$C_6H_5-\underset{\displaystyle OH}{\underset{|}{CH}} - \overset{\displaystyle CH_3}{\overset{|}{\underset{\displaystyle CH_3}{\underset{|}{C}}}} - CO_2H,$$

is obtained.

The condensation is closely analogous to the aldol condensation.

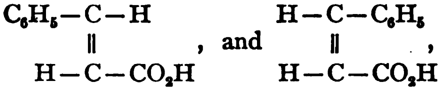
2. By heating benzal chloride with sodium acetate:

$$C_6H_5CHCl_2 + CH_3CO_2Na = C_6H_5CH = CH - CO_2H \\ + NaCl + HCl.$$

This method is of commercial importance.

3. By condensation of benzaldehyde with acetone to benzalacetone, $C_6H_5CH = CH\text{–}COCH_3$ (p. 190), followed by oxidation to cinnamic acid and chloroform, $CHCl_3$, by means of sodium hypochlorite (p. 199).

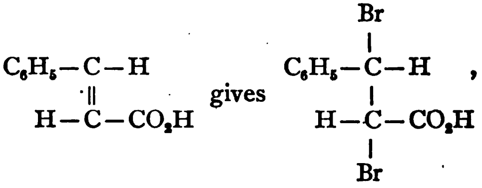
In addition to the ordinary cinnamic acid, two other forms, known as "allo-cinnamic acid" and "isocinnamic acid," are known. Theory leads us to expect two stereomeric forms,



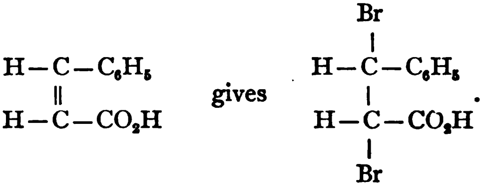
$$\begin{array}{c} C_6H_5-C-H \\ \| \\ H-C-CO_2H \end{array} ,\ \text{and}\ \begin{array}{c} H-C-C_6H_5 \\ \| \\ H-C-CO_2H \end{array} ,$$

but the nature of the third form has not been satisfactorily explained.*

Cinnamic acid and allocinnamic acid give different dibromides, $C_6H_5CHBrCHBrCO_2H$, the first melting at 201°, the second at 91°–93°. This can be explained as follows, if we consider the order of the atoms and groups in the formulae as representing the order of the groups around the carbon atoms:



$$\begin{array}{c} C_6H_5-C-H \\ \| \\ H-C-CO_2H \end{array} \ \text{gives}\ \begin{array}{c} Br \\ | \\ C_6H_5-C-H \\ | \\ H-C-CO_2H \\ | \\ Br \end{array} ,$$



$$\begin{array}{c} H-C-C_6H_5 \\ \| \\ H-C-CO_2H \end{array} \ \text{gives}\ \begin{array}{c} Br \\ | \\ H-C-C_6H_5 \\ | \\ H-C-CO_2H \\ | \\ Br \end{array} .$$

A consideration of these formulae reveals the fact that rotations around the line joining the two carbon atoms can-

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* Bulmann has shown that allocinnamic acid and the two isocinnamic acids differ only in crystalline form, and are probably identical in structure. (*Ber. d. chem. Ges.* 42, 182.)

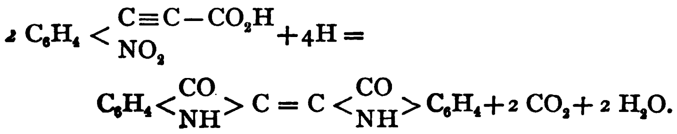
not bring the two dibromides into positions which are identical. Thus, rotation of the upper carbon atom in the first dibromide till the hydrogen atoms are over each other will leave a bromine atom over the carboxyl, and the phenyl group over the other bromine atom, relations which are different from those of the second dibromide. This can be most easily seen by the use of models. It is evident from this that when two adjacent carbon atoms each bear three different groups, the order of those groups may be the cause of isomerism. Isomers of this kind often exhibit differences in chemical as well as in physical properties.

Phenyl Propiolic Acid, $C_6H_5C\equiv C-CO_2H$, is prepared by treating the ethyl ester of cinnamic dibromide with alcoholic potash.

$$C_6H_5CHBrCHBrCO_2C_2H_5+3KOH=C_6H_5C\equiv C-CO_2K$$
$$+2KBr+2\,H_2O+C_2H_5OH$$

Phenyl propiolic acid decomposes, on heating with water to 120°, into carbon dioxide and phenyl acetylene, $C_6H_5\equiv CH$. It is to be noticed that the grouping, $-C\equiv C-CO_2H$, found in phenyl propiolic acid, produces an instability similar to that caused by the grouping $-CO-CH_2CO_2H$ (p. 351), though perhaps somewhat less in degree.

Phenyl propiolic acid is also of interest because of the ready conversion of orthonitrophenylpropiolic acid into indigo by merely heating it with grape sugar and caustic soda.

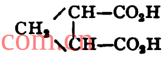
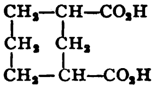
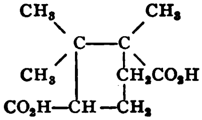
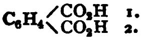
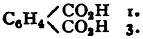
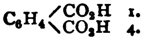


$$2\,C_6H_4<\begin{matrix}C\equiv C-CO_2H\\NO_2\end{matrix}+4H=$$
$$C_6H_4<\begin{matrix}CO\\NH\end{matrix}>C=C<\begin{matrix}CO\\NH\end{matrix}>C_6H_4+2\,CO_2+2\,H_2O.$$

Indigo.

BIBASIC ACIDS.

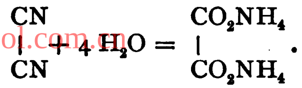
		MELTING POINT.
Oxalic acid	$\begin{array}{l}CO_2H\\ \vert\\ CO_2H\end{array}$	101.5°
Malonic acid	$CH_2{<}\begin{array}{l}CO_2H\\ CO_2H\end{array}$	133°
Succinic acid	$\begin{array}{l}CH_2\text{—}CO_2H\\ \vert\\ CH_2\text{—}CO_2H\end{array}$	185°
Isosuccinic acid	$CH_3\text{—}CH{<}\begin{array}{l}CO_2H\\ CO_2H\end{array}$	130°
Glutaric acid	$CH_2{<}\begin{array}{l}CH_2\text{—}CO_2H\\ CH_2\text{—}CO_2H\end{array}$	97.5°
Pyrotartaric acid (Methyl succinic acid)	$\begin{array}{l}CH_3\text{—}CH\text{—}CO_2H\\ \quad\;\;\vert\\ \quad\;\;CH_2\text{—}CO_2H\end{array}$	112°
Adipic acid	$\begin{array}{l}CH_2\text{—}CH_2\text{—}CO_2H\\ \vert\\ CH_2\text{—}CH_2\text{—}CO_2H\end{array}$	149°
Symmetric dimethyl-succinic acid (Fumaroid form)	$\begin{array}{l}CH_3\text{—}CH\text{—}CO_2H\\ \qquad\;\vert\\ CH_3\text{—}CH\text{—}CO_2H\end{array}$	195°
The same (Maleïnoid form)	"	124°
Pimelic acid	$CH_2{<}\begin{array}{l}CH_2\text{—}CH_2CO_2H\\ CH_2\text{—}CH_2CO_2H\end{array}$	105°
Trimethylsuccinic acid	$\begin{array}{l}CH_3\text{—}CH\text{—}CO_2H\\ \qquad\quad\vert\\ {CH_3 \atop CH_3}{>}\,C\text{—}CO_2H\end{array}$	152°
Suberic acid (Ger. Korksäure)	$(CH_2)_6{<}\begin{array}{l}CO_2H\\ CO_2H\end{array}$	140°
Azelaic acid	$(CH_2)_7{<}\begin{array}{l}CO_2H\\ CO_2H\end{array}$	106°
Sebacic acid	$(CH_2)_8{<}\begin{array}{l}CO_2H\\ CO_2H\end{array}$	133°
Fumaric acid	$\begin{array}{l}CO_2H\text{—}CH\\ \qquad\quad\Vert\\ \qquad\;HC\text{—}CO_2H\end{array}$	Sublimes at 200°
Maleïc acid	$\begin{array}{l}H\text{—}C\text{—}CO_2H\\ \quad\;\Vert\\ H\text{—}C\text{—}CO_2H\end{array}$	130°
Mesaconic acid	$\begin{array}{l}CO_2H\text{—}C\text{—}CH_3\\ \qquad\quad\Vert\\ \qquad H\text{—}C\text{—}CO_2H\end{array}$	202°
Citraconic acid	$\begin{array}{l}CH_3\text{—}C\text{—}CO_2H\\ \qquad\;\Vert\\ \quad\;\;HC-CO_2H\end{array}$	80°
Itaconic acid	$\begin{array}{l}CH_2{=}C\text{—}CO_2H\\ \qquad\;\vert\\ \qquad\;CH_2\text{—}CO_2H\end{array}$	161°
Glutaconic acid	$CH{\lessgtr}\begin{array}{l}CH\text{—}CO_2H\\ CH_2\text{—}CO_2H\end{array}$	132°
Cyclopropane 1.1 dicarboxylic acid	$\begin{array}{l}CH_2\\ \vert\\ CH_2\end{array}{>}C{<}\begin{array}{l}CO_2H\\ CO_2H\end{array}$	140°

		MELTING POINT.
Cyclopropane 1.2 dicarboxylic acid (Cis form)		139°
The same (Trans form)	"	175°
Hexahydroisophthalic acid (Cis form)		163°
The same (Trans form)	"	120°
Camphoric acid (Cis form, active)		187°
Isocamphoric acid (Trans form, active)	"	172°
Phthalic acid	 $C_6H_4\langle\begin{array}{l}CO_2H \quad 1.\\ CO_2H \quad 2.\end{array}$	184°
Isophthalic acid	 $C_6H_4\langle\begin{array}{l}CO_2H \quad 1.\\ CO_2H \quad 3.\end{array}$	Above 300°
Terephthalic acid	 $C_6H_4\langle\begin{array}{l}CO_2H \quad 1.\\ CO_2H \quad 4.\end{array}$	Sublimes

The acids of this table have been selected chiefly for the purpose of illustrating the fundamental forms and the possibilities of isomerism.

Oxalic Acid, $\begin{array}{l}CO_2H\\ |\\ CO_2H\end{array} + 2\ H_2O$, is comparatively stable toward oxidizing agents, and so is frequently formed by the oxidation of carbon compounds. Especially, it may be prepared readily by the oxidation of cane-sugar with nitric acid. It is prepared, technically, by heating sawdust with a mixture of caustic potash and caustic soda, the oxalic acid being formed from the cellulose.

Oxalic acid is also formed from an aqueous solution of cyanogen on standing.



$$\begin{array}{c}CN\\|\\CN\end{array} + 4H_2O = \begin{array}{l}CO_2NH_4\\|\\CO_2NH_4\end{array}.$$

Oxalic acid crystallizes with two molecules of water. It is quite possible that the crystallized acid has the structure, $\begin{array}{l}C(OH)_3\\|\\C(OH)_3\end{array}$, since the presence of strongly negative atoms or groups increases the stability of compounds having two or more hydroxyl groups combined with one carbon atom.

Oxalic acid is a "strong" acid, the strongest indeed of the organic acids, as shown by the conductivity which gives $K =$ about 10.

By careful heating, oxalic acid can be partly sublimed. If heated to a higher temperature, it is decomposed partly into formic acid and carbon dioxide, chiefly into carbon dioxide, carbon monoxide and water. The latter products are also formed when it is heated with concentrated sulphuric acid.

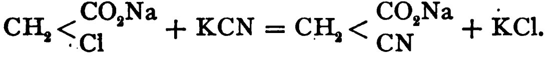
Toward nitric acid oxalic acid is comparatively stable. Potassium permanganate, or manganese dioxide, oxidizes it quantitatively to carbon dioxide in a warm acid solution. On this account either crystallized oxalic acid or ammonium oxalate, $(NH_4)_2C_2O_4 + H_2O$, can be used in standardizing permanganate solutions, or in determining the value of commercial manganese dioxide for the generation of chlorine.

Oxalic acid forms neutral and acid salts, and also salts in which but one atom of hydrogen in two molecules of the acid is replaced. Potassium "tetroxalate," $KHC_2O_4.H_2C_2O_4 + H_2O$, which belongs to the last class, is sometimes used as a standard in preparing normal alkali solutions.

The oxalates of the metals other than the alkali metals are mostly insoluble or difficultly soluble. Many of the metals, however, form double oxalates with potassium, sodium, or ammonium, and these are often easily soluble.

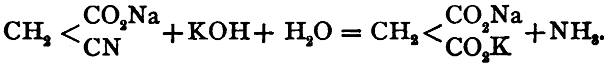
Potassium ferrous oxalate, $K_2Fe(C_2O_4)_2 + H_2O$, is a powerful reducing agent, and is used as a developer in photography.

Malonic Acid, $CH_2<\begin{matrix}CO_2H\\ CO_2H\end{matrix}$, is prepared from chloracetic acid.



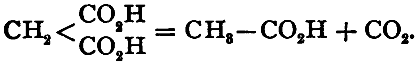
$$CH_2<\begin{matrix}CO_2Na\\ Cl\end{matrix} + KCN = CH_2<\begin{matrix}CO_2Na\\ CN\end{matrix} + KCl.$$

Sodium salt of cyanacetic acid.



$$CH_2<\begin{matrix}CO_2Na\\ CN\end{matrix} + KOH + H_2O = CH_2<\begin{matrix}CO_2Na\\ CO_2K\end{matrix} + NH_3.$$

Malonic acid crystallizes in triclinic plates. It melts at 133°–134°. When heated to 140°–150° it decomposes quantitatively into carbon dioxide and acetic acid.



$$CH_2<\begin{matrix}CO_2H\\ CO_2H\end{matrix} = CH_3-CO_2H + CO_2.$$

All derivatives of malonic acid having two carboxyl groups combined with the same carbon atom decompose in a similar manner at some temperature below 200°. The combination of two carboxyl groups with a single carbon atom causes instability, very much as the combination of two hydroxyl groups with a single carbon atom does, but the temperature of decomposition is higher. It is noticeable that the grouping $R-CO-CH_2-CO_2H$ is still more unstable (p. 351).

If the solution of potassium cyanacetate and potassium chloride, obtained by the first reaction above, is evaporated nearly to dryness, and the residue heated with a mixture of sulphuric acid and alcohol, the *diethyl ester of malonic acid* is formed.*

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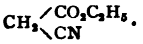
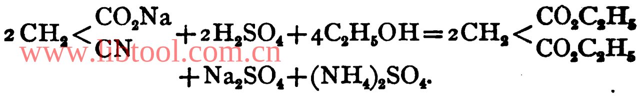
* The malonic ester prepared in this way contains, also, some cyanacetic ester,



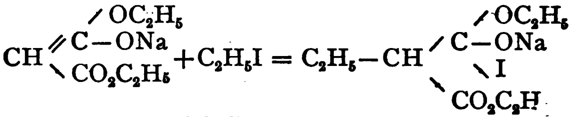
$$CH_2<\begin{matrix}CO_2C_2H_5\\ CN\end{matrix}.$$



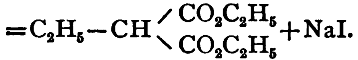
$$2\,CH_2{<}{\begin{matrix}CO_2Na\\ CN\end{matrix}} + 2H_2SO_4 + 4C_2H_5OH = 2CH_2{<}{\begin{matrix}CO_2C_2H_5\\ CO_2C_2H_5\end{matrix}} + Na_2SO_4 + (NH_4)_2SO_4.$$

Malonic ester can be distilled without decomposition, though its boiling point is 198.°

Condensations with Malonic Ester. — This ester has a very unusual interest because of its use for syntheses. When it is added to an alcoholic solution of sodium ethylate, C_2H_5ONa, a sodium salt is formed. To this salt the formula $CHNa{<}{\begin{matrix}CO_2C_2H_5\\ CO_2C_2H_5\end{matrix}}$ is often assigned. It seems more probable, however, that it has the formula $CH{\begin{matrix}\diagup\!\!\diagup C{\begin{matrix}\diagup OC_2H_5\\ -ONa\end{matrix}}\\ \diagdown CO_2C_2H_5\end{matrix}}$. When an alkyl halide or halogen derivative of some carbon compound is added to this sodium salt, a derivative of malonic ester is formed. Thus,



$$CH{\begin{matrix}\diagup\!\!\diagup C{\begin{matrix}\diagup OC_2H_5\\ -ONa\end{matrix}}\\ \diagdown CO_2C_2H_5\end{matrix}} + C_2H_5I = C_2H_5-CH{\begin{matrix}\diagup C{\begin{matrix}\diagup OC_2H_5\\ -ONa\\ \diagdown I\end{matrix}}\\ \diagdown CO_2C_2H\end{matrix}}$$



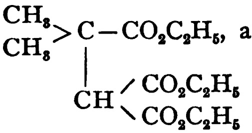
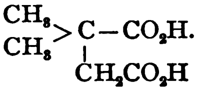
$$= C_2H_5-CH{\begin{matrix}\diagup CO_2C_2H_5\\ \diagdown CO_2C_2H_5\end{matrix}} + NaI.$$

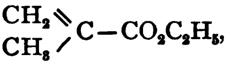
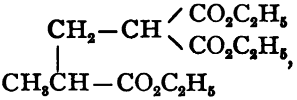
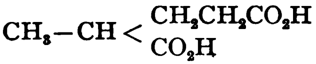
Diethyl ester of ethyl malonic acid.

By saponifying this compound, ethyl malonic acid, $C_2H_5CH < {\begin{matrix}CO_2H\\ CO_2H\end{matrix}}$, is formed, and this gives, on heating (see above), normal butyric acid, $C_2H_5CH_2CO_2H$.

This method of synthesis is closely related to that in which acetacetic ester is used (p. 350), and has proved useful for the preparation of a great variety of compounds. In some cases cyanacetic ester, $CH_2{<}{\begin{matrix}CO_2C_2H_5\\ CN\end{matrix}}$, can be employed with advantage in place of malonic ester. (See below.)

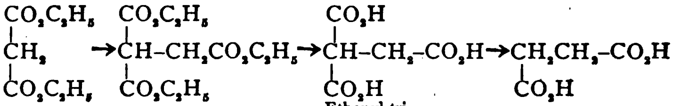
The second hydrogen atom of the CH_2 group in malonic ester or cyanacetic ester may be replaced by an alkyl group in the same manner as the first.

Malonic ester also adds itself to Δ^1 unsaturated acids, in the presence of sodium ethylate, forming condensation products in which the malonic ester group attaches itself to the β-carbon atom. Occasionally halogen derivatives which are easily decomposed give the product derived from the unsaturated acid, as well as the normal product. Thus, the normal condensation product of malonic ester, sodium ethylate, and α-bromisobutyric ester,  $\begin{matrix}CH_3\\CH_3\end{matrix}\!>CBrCO_2C_2H_5$, is  $\begin{array}{l}\begin{matrix}CH_3\\CH_3\end{matrix}\!>C-CO_2C_2H_5\\ \qquad\quad |\\ \qquad\quad CH<\begin{matrix}CO_2C_2H_5\\CO_2C_2H_5\end{matrix}\end{array}$, and this would give, by saponification and splitting off of carbon dioxide, dimethyl succinic acid,  $\begin{array}{l}\begin{matrix}CH_3\\CH_3\end{matrix}\!>C-CO_2H.\\ \qquad\quad |\\ \qquad\quad CH_2CO_2H\end{array}$

In addition to this, however, a considerable portion of the bromisobutyric ester first loses hydrobromic acid and the resulting ester,  $\begin{matrix}CH_2\\CH_3\end{matrix}\!>C-CO_2C_2H_5$, then adds malonic ester giving the compound,  $\begin{array}{l}CH_2-CH<\begin{matrix}CO_2C_2H_5\\CO_2C_2H_5\end{matrix}\\ |\\ CH_3CH-CO_2C_2H_5\end{array}$, and this, by saponification and loss of carbon dioxide, gives *a-methylglutaric acid*,  $CH_3-CH<\begin{matrix}CH_2CH_2CO_2H\\CO_2H\end{matrix}$. In this case cyanacetic ester gives almost exclusively the normal product, and hence is much more suitable for the synthesis when dimethyl succinic acid is desired. (Bone and Sprankling, *J. Chem. Soc.* (London), 75, 845.)

Succinic Acid, $\begin{array}{l}CH_2-CO_2H\\|\\CH_2-CO_2H\end{array}$, is found in amber, as is indicated by its name. It can be prepared, synthetically, from ethylene bromide, CH_2BrCH_2Br, by converting this into ethylene cyanide, $\begin{array}{l}CH_2-CN\\|\\CH_2-CN\end{array}$, and saponifying the latter.

Another synthetic method consists in condensing malonic ester with chloracetic ester, $ClCH_2-CO_2C_2H_5$, by the methods just given. This gives the series: —

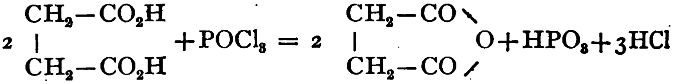


$$\begin{array}{l}CO_2C_2H_5\\|\\CH_2\\|\\CO_2C_2H_5\end{array} \rightarrow \begin{array}{l}CO_2C_2H_5\\|\\CH-CH_2CO_2C_2H_5\\|\\CO_2C_2H_5\end{array} \rightarrow \begin{array}{l}CO_2H\\|\\CH-CH_2-CO_2H\\|\\CO_2H\end{array} \rightarrow \begin{array}{l}CH_2CH_2-CO_2H\\|\\CO_2H\end{array}$$

Ethenyl tricarboxylic acid.

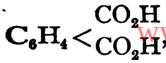
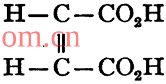
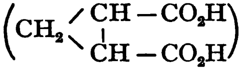
Succinic acid can also be prepared by reducing tartaric acid with hydriodic acid (p. 332).

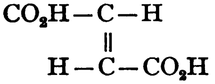
If succinic acid is heated somewhat above 200°, or if it is treated with phosphorus pentachloride, phosphorus oxychloride, acetyl chloride, or other dehydrating agents, it gives an "inner" anhydride, which evidently contains a ring of four carbon atoms and one oxygen atom,

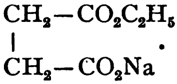


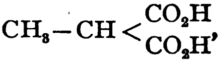
$$2\begin{array}{l}CH_2-CO_2H\\|\\CH_2-CO_2H\end{array} + POCl_3 = 2\begin{array}{l}CH_2-CO\diagdown\\|\qquad\qquad\quad O\\CH_2-CO\diagup\end{array} + HPO_3 + 3HCl$$

All of the derivatives of succinic acid with an open chain form similar anhydrides on merely heating to about 200° (Auwers, *Ann. d. Chem.* 285, 223). Orthophthalic acid,

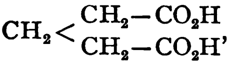
 $C_6H_4<\begin{matrix}CO_2H\\CO_2H\end{matrix}$, maleic acid,  $\begin{matrix}H-C-CO_2H\\ \|\\ H-C-CO_2H\end{matrix}$, and its derivatives, the "cis" forms of the 1,2 dicarboxylic acids of cyclopropane  $\left(CH_2\begin{matrix}/CH-CO_2H\\ |\\ \backslash CH-CO_2H\end{matrix}\right)$ and cyclobutane, and both "cis" and "trans" forms of the similar acids of cyclopentane and cyclohexane, form similar inner anhydrides.

Fumaric acid,  $\begin{matrix}CO_2H-C-H\\ \|\\ H-C-CO_2H\end{matrix}$, and the "trans" forms of the 1,2-dicarboxylic acids of cyclopropane and cyclobutane, form no similar anhydrides. These facts are significant in their relation to the structure of these acids.

Succinic anhydride gives, with sodium ethylate, sodium ethyl succinate,  $\begin{matrix}CH_2-CO_2C_2H_5\\ |\\ CH_2-CO_2Na\end{matrix}$.

Isosuccinic Acid (methyl malonic acid),  $CH_3-CH<\begin{matrix}CO_2H\\CO_2H\end{matrix}$, may be prepared by the malonic ester synthesis from malonic acid, or from α-brompropionic acid, $CH_3CHBrCO_2H$, by the same methods used for the preparation of malonic acid.*

Isosuccinic acid decomposes, on heating, into propionic acid and carbon dioxide.

Glutaric Acid,  $CH_2<\begin{matrix}CH_2-CO_2H\\CH_2-CO_2H\end{matrix}$, can be prepared from trimethylene bromide (1,3 dibrompropane), $CH_2BrCH_2CH_2Br$, through the cyanide. Also by the condensation of formaldehyde with malonic ester, under the influence of a little diethylamine, followed by the saponification of the resulting dicarboxylglutaric ester, and decomposition of the tetra-

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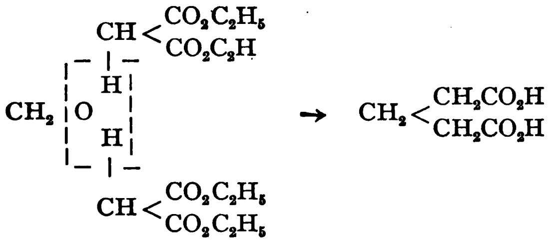
* The student will do well to write the reactions implied in these statements.

basic acid which is formed. (Knoevenagel, *Ber. d. chem. Ges.* **27**, 2346.)



$$\begin{array}{ll} & CH<^{CO_2C_2H_5}_{CO_2C_2H} \\ & \quad H \\ CH_2 & O \\ & \quad H \\ & CH<^{CO_2C_2H_5}_{CO_2C_2H_5} \end{array} \rightarrow CH_2<^{CH_2CO_2H}_{CH_2CO_2H}$$

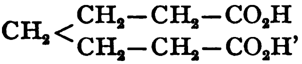
Glutaric acid yields an anhydride, $CH_2<^{CH_2-CO}_{CH_2-CO}>O$, on warming with acetyl chloride, but forms one only slowly when heated to 290°. The "cis" forms of the 1,3 cyclobutane, cyclopentane, and cyclohexane dicarboxylic acids produce anhydrides, while the "trans" forms of the same acids do not.

Adipic Acid, $\begin{array}{l} CH_2-CH_2-CO_2H \\ | \\ CH_2-CH_2-CO_2H \end{array}$, is formed, along with other acids, by the oxidation of natural fats. It is best prepared by the oxidation of the cyclohexane of Russian or Californian petroleum with strong nitric acid. It is also formed by the electrolysis of the potassium salt of the acid ester of succinic acid, $\begin{array}{l} CH_2-CO_2C_2H_5 \\ | \\ CH_2-CO_2K \end{array}$. Two of the ions, $\begin{array}{l} CH_2-CO_2C_2H_5 \\ | \\ CH_2-CO_2. \end{array}$, liberated by the electrolysis, decompose with loss of carbon dioxide, and the residues combine to form adipic ester, $\begin{array}{l} CH_2-CH_2-CO_2C_2H_5 \\ | \\ CH_2-CH_2-CO_2C_2H_5 \end{array}$. (Brown and Walker, *Ann. Chem.* (Liebig) **261**, 117.)

Adipic acid forms no inner anhydride. It melts at 149°, and boils without decomposition at 265°, under a pressure of 100 mm.

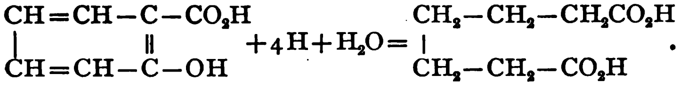
When calcium adipate is distilled, cyclopentanone is formed (p. 192).

Pimelic Acid,



$$CH_2<\begin{matrix}CH_2-CH_2-CO_2H\\CH_2-CH_2-CO_2H\end{matrix},$$

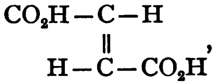
is most easily prepared by the reduction of salicylic acid by means of alcohol and sodium.



$$\begin{matrix}CH=CH-C-CO_2H\\ | \qquad\qquad \| \\ CH=CH-C-OH\end{matrix} +4H+H_2O= \begin{matrix}CH_2-CH_2-CH_2CO_2H\\ | \\ CH_2-CH_2-CO_2H\end{matrix}.$$

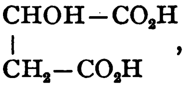
Pimelic acid forms no inner anhydride, but the distillation of its calcium salt gives cyclohexanone (p. 192).

Fumaric Acid,



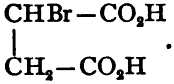
$$\begin{matrix}CO_2H-C-H\\ \|\\ H-C-CO_2H\end{matrix},$$

is formed by heating malic acid,



$$\begin{matrix}CHOH-CO_2H\\ |\\ CH_2-CO_2H\end{matrix},$$

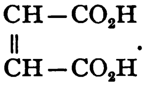
or bromsuccinic acid,



$$\begin{matrix}CHBr-CO_2H\\ |\\ CH_2-CO_2H\end{matrix}.$$

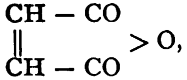
It is difficultly soluble in water. When heated to 200°, it sublimes without melting. When heated to a higher temperature it partly decomposes, and is partly converted into maleïc anhydride. It is also converted into maleïc anhydride by warming to 100° with acetyl chloride and acetic acid.

Maleïc Acid,



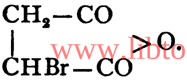
$$\begin{matrix}CH-CO_2H\\ \|\\ CH-CO_2H\end{matrix}.$$

The anhydride of maleïc acid,



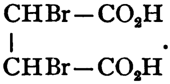
$$\begin{matrix}CH-CO\\ \|\\ CH-CO\end{matrix}>O,$$

is formed by distilling malic acid, fumaric acid, or by heating monobromsuccinic anhydride,



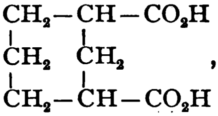
Maleïc acid melts at 130°, and is very easily soluble in water. By heating in a vacuum at 100°, it is readily converted into its anhydride.

Fumaric and maleïc acid are supposed to represent a "cis" and "trans" stereoisomerism similar to that of the crotonic acids. The "cis" formula is given to maleïc acid because of the ease with which it forms an anhydride.

Fumaric and maleïc acid give, with bromine, two isomeric bibromsuccinic acids,  $\begin{array}{l} CHBr-CO_2H \\ | \\ CHBr-CO_2H \end{array}$. Their relation to each other is, apparently, similar to the relation between the two cinnamic acid dibromides (p. 246).

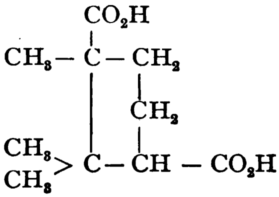
Mesaconic, Citraconic, Itaconic, and Glutaconic Acids are isomeric acids, whose relationships are apparent from the formulae given in the table.

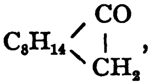
Hexahydroisophthalic Acid,

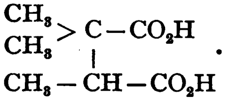


has been referred to (p. 100) because of the interest which attaches to it in establishing the formula for benzene. It exists in both the "cis" and "trans" form. Only the "cis" form gives an anhydride.

Camphoric Acid,

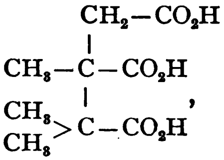


is prepared by the oxidation of camphor,  $C_8H_{14}\left\langle\begin{matrix}CO\\|\\CH_2\end{matrix}\right.$, by means of nitric acid. It is of interest because it is chiefly through a study of camphoric acid that the structure of camphor has been established. Only an outline of the more important steps in the establishment of the formula can be given. When camphoric acid is further oxidized it gives a tribasic acid, camphoronic acid, $C_6H_{11}(CO_2H)_3$. Camphoronic acid gives, when heated, trimethyl succinic acid,



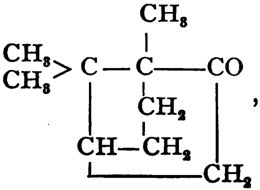
$$\begin{matrix} \begin{matrix}CH_3\\CH_3\end{matrix}\!> C-CO_2H \\ | \\ CH_3-CH-CO_2H \end{matrix} .$$

This led Bredt, in 1893, to propose the formula,

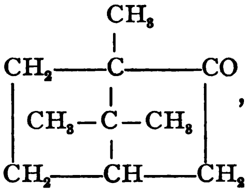


$$\begin{matrix} & CH_2-CO_2H \\ & | \\ CH_3- & C-CO_2H \\ & | \\ \begin{matrix}CH_3\\CH_3\end{matrix}\!> & C-CO_2H\end{matrix} ,$$

for camphoronic acid, and the formula,



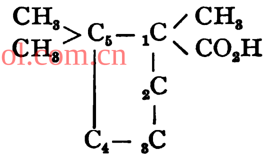
, or



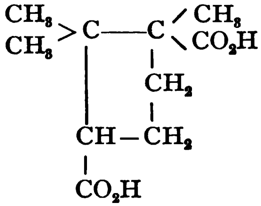
,

for camphor.

Perkin prepared camphoronic acid synthetically a few years later, and so demonstrated the truth of Bredt's formula for that acid. Since camphoric acid is, in all of its properties, a saturated compound, it must contain a ring of carbon atoms, and the only possible grouping consistent with the formula of camphoronic acid must contain the skeleton

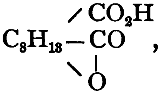
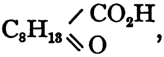


The only question remaining was as to whether the second carboxyl group is combined with the carbon atom numbered 2, 3, or 4. The evidence upon this last point is not all of it consistent, but at present is almost conclusively in favor of the formula,

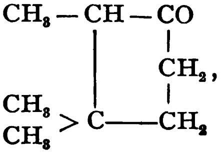


The most important facts favoring this structure are.

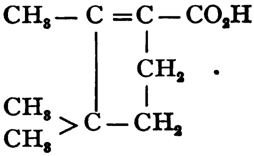
1. Isocamphoric acid forms no anhydride, thus resembling hexahydroisophthalic acid, and not hexahydrophthalic acid.

2. Camphanic acid,  $C_8H_{13}\begin{array}{l}\diagup CO_2H\\ -CO\\ \diagdown \mid\\ \quad O\end{array}$, gives by simple reaction a ketonic acid,  $C_8H_{13}\begin{array}{l}\diagup CO_2H\\ \diagdown\diagdown O\end{array}$, which evidently contains oxygen in place of the carboxyl and hydrogen atoms which are attached to the carbon atom 4 above, since the acid is stable, while if the oxygen were in position 2 the acid would be unstable. This excludes position 2 for the second carboxyl.

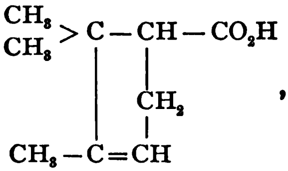
3. 2,33-trimethylcyclopentanone,



has been prepared synthetically, and also from β-campholytic acid by a series of reactions which demonstrate that the acid has the structure,

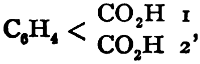


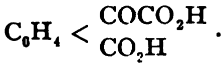
α-Campholytic acid, $C_8H_{13}CO_2H$, retains the secondary carboxyl of camphoric acid, and can be converted easily to β-campholytic acid by warming with dilute acids. But when α-campholytic is reduced to the acid, $C_8H_{15}CO_2H$, and the carboxyl and a hydrogen atom of the latter are replaced by oxygen, the resulting cyclic ketone is different from the 2,33-trimethylcyclopentanone. The structure of the α-campholytic acid, which is nearest to that of camphor, must be different, therefore, from that of the β-campholytic acid, and is, undoubtedly,



the transformation of it into β-campholytic acid involving a transfer of a methyl group from one carbon atom to another. Such a structure is probable only in case the second carboxyl group of camphoric acid occupies position 4.

4. The synthesis of camphoric acid has been effected by Komppa (*Ber. d. chem. Ges.* 36, 4332), and by Perkin (*J. Chem. Soc.* 89, 795) by methods which establish its structure but which cannot be given in detail here.

Phthalic Acid,  $C_6H_4 < {CO_2H \; 1 \atop CO_2H \; 2}$, is prepared, practically, by the oxidation of naphthalene. In the laboratory this is most easily effected by means of potassium permanganate, which yields, in an alkaline solution, *phthalonic acid*,

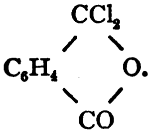


$$C_6H_4 < \begin{matrix} COCO_2H \\ CO_2H \end{matrix} .$$

This may be considered as a derivative of oxalic acid, and is readily oxidized to phthalic acid by means of manganese dioxide in an acid solution. Commercially, phthalic acid is prepared on a large scale by the oxidation of naphthalene fuming sulphuric acid.* Phthalic acid can also be prepared by the oxidation of orthoxylene, but not easily (p. 243).

When heated, phthalic acid is converted into an *anhydride*, $C_6H_4 < \begin{matrix} CO \\ CO \end{matrix} > O$, which melts at 128°, and boils without decomposition at 284°.

When phthalic anhydride is warmed with phosphorus pentachloride it is converted into *phthalyl chloride*, which appears, for the following reasons, to have, not the ordinary structure of an acid chloride, $C_6H_4 < \begin{matrix} COCl \\ COCl \end{matrix}$, but the unsymmetrical structure,



When the chloride is reduced by means of zinc and hydrochloric acid it gives *phthalid*, $C_6H_4 < \begin{matrix} CH_2 \\ CO \end{matrix} > O$, a lactone (p. 318). Again, when the chloride is treated with benzene and aluminium chloride two phenyl groups are introduced in place of the chlorine. By reducing the resulting compound with

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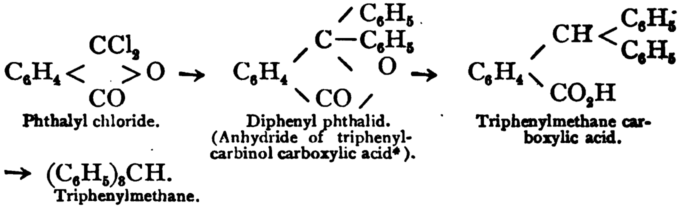
* 100 parts naphthalene, 1500 parts sulphuric acid monohydrate, and fifty parts of mercuric sulphate are heated gradually from 200° to 250° and 300° till the phthalic anhydride has distilled. D. R. P. No. 91,202.

zinc dust in an alkaline solution, a triphenylmethane carboxylic acid is obtained, and distillation of this with barium hydroxide gives triphenylmethane itself. These facts can be satisfactorily explained only by the following formulae:



$$C_6H_4<\overset{CCl_2}{\underset{CO}{}}>O \rightarrow C_6H_4\begin{matrix}/C(C_6H_5)_2\\ \quad\backslash O\\ \backslash CO/\end{matrix} \rightarrow C_6H_4\begin{matrix}/CH<^{C_6H_5}_{C_6H_5}\\ \backslash CO_2H\end{matrix} \rightarrow (C_6H_5)_3CH.$$

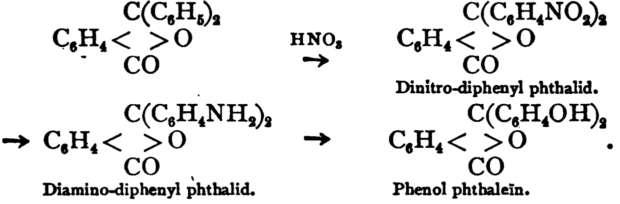
Phthalyl chloride. **Diphenyl phthalid.** (Anhydride of triphenylcarbinol carboxylic acid*). **Triphenylmethane carboxylic acid.** Triphenylmethane.

Phenol Phthaleïn.—When a mixture of phenol and phthalic anhydride is warmed with concentrated sulphuric acid, ***phenol phthaleïn*** is formed,

$$2\,C_6H_5OH + C_6H_4<^{CO}_{CO}>O = C_{20}H_{14}O_4 + H_2O.$$

Phenol. **Phthalic anhydride.** **Phenol phthaleïn.**

When diphenyl phthalid, $C_6H_4<\overset{C(C_6H_5)_2}{\underset{CO}{}}>O$, is treated with nitric acid a dinitro compound is produced. This, by reduction, gives a diamino compound, and that, with nitrous acid, yields phenol phthaleïn. This demonstrates the structure of the phenol phthaleïn, as will be apparent from the following:



$$C_6H_4<\overset{C(C_6H_5)_2}{\underset{CO}{}}>O \xrightarrow{HNO_3} C_6H_4<\overset{C(C_6H_4NO_2)_2}{\underset{CO}{}}>O$$

Dinitro-diphenyl phthalid.

$$\rightarrow C_6H_4<\overset{C(C_6H_4NH_2)_2}{\underset{CO}{}}>O \rightarrow C_6H_4<\overset{C(C_6H_4OH)_2}{\underset{CO}{}}>O.$$

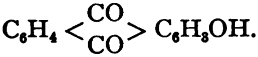
Diamino-diphenyl phthalid. **Phenol phthaleïn.**

---

* **This name represents the acid, $C\begin{matrix}\leqslant(C_6H_5)_2\\ -C_6H_4CO_2H\\ \backslash OH\end{matrix}$, as a derivative of *triphenyl carbinol,* $(C_6H_5)_3COH$. *Carbinol* is a name synonymous with methyl alcohol, CH_3OH.**

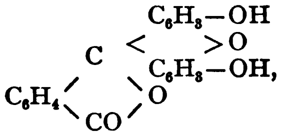
Phenol phthaleïn is colorless, and undergoes practically no ionization in pure water. With alkalies it forms salts which ionize in water, and the ion, $C_{20}\overline{H_{13}}O_4$ or $C_{20}\overline{\overline{H_{12}}}O_4$, is, apparently, deep red in color.* As an unusually small number of hydrogen ions will prevent this ionization, phenol phthaleïn is especially suited for use as an indicator in titrating organic acids which undergo but little ionization. The same fact, however, makes it sensitive to the presence of carbonic acid, and it is necessary to use a standard alkali which is free from carbonates.

When phenol phthaleïn is heated to 200° with sulphuric acid it is converted into hydroxyanthraquinone,



$$C_6H_4<\begin{matrix}CO\\CO\end{matrix}>C_6H_3OH.$$

Fluoresceïn.—By condensing resorcinol, $C_6H_4<\begin{matrix}OH & 1\\OH & 3\end{matrix}$, with phthalic anhydride, *fluoresceïn*,



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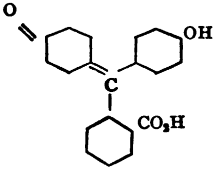
* This difference in color between solutions of the salt and of the acid has led some authors to consider that the salt is derived from an acid having a quinoid structure.



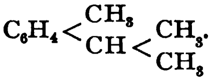
A number of other facts pointing to this conclusion are known, but a discussion of them would lead too far. See Orndorff, *Am. Chem. J.* 26, 110. Also, Stieglitz, *J. Am. Chem. Soc.* 24, 590. It seems altogether probable that in many cases the peculiar conduct of indicators is due to a change in the ionization, which is associated with a difference in structure between a salt and the corresponding "pseudo acid" (p. 288).

is formed. This gives, with bromine, *tetra-bromfluoresceïn* (*eosin*). Compounds of the type of fluoresceïn are only formed when the two hydroxyl groups of the phenol are in the meta position and the third meta hydrogen of the phenol has not been replaced.

Eosin and similar compounds, and also derivatives of anthraquinone prepared from phthaleïns, are used as dyes.

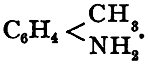
Isophthalic Acid, $C_6H_4<\begin{array}{l}CO_2H\ 1\\CO_2H\ 3\end{array}$, is formed by the oxidation of metaxylene, or of any hydrocarbon having two side chains in the meta position. It may also be prepared from meta-aminobenzoic acid, $C_6H_4<\begin{array}{l}CO_2H\\NH_2\end{array}$, through the diazo compound and the cyanide (see p. 461). Isophthalic acid melts above 300°, and yields no anhydride. The "cis" form of *hexahydro-isophthalic acid*, however, gives an anhydride.

Terephthalic Acid, $C_6H_4<\begin{array}{l}CO_2H\ 1\\CO_2H\ 4\end{array}$, is formed by the oxidation of paraxylene, $C_6H_4<\begin{array}{l}CH_3\\CH_3\end{array}$, or cymene,



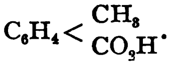
$$C_6H_4<\begin{array}{l}CH_3\\CH<\begin{array}{l}CH_3\\CH_3\end{array}\end{array}.$$

It is most easily prepared from paratoluidine,



$$C_6H_4<\begin{array}{l}CH_3\\NH_2\end{array}.$$

This, through the diazo compound and cyanide (p. 461), gives paratoluic acid,

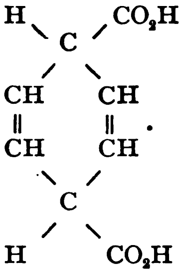


$$C_6H_4<\begin{array}{l}CH_3\\CO_2H\end{array}.$$

The latter, by oxidation with potassium permanganate, gives terephthalic acid. Terephthalic acid is almost insoluble in water. When heated, it sublimes without melting.

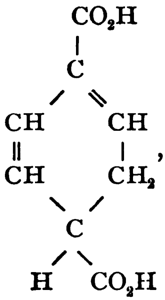
Reduction Products of Terephthalic Acid. — Terephthalic acid can be readily reduced by means of sodium amalgam, and the reduction products have an especial interest, partly because they illustrate so clearly the possibilities of isomerism in compounds of this class, and partly because of the bearing which they have on the structure of benzene.

The first reduction product is the $\Delta^{2,5}$ *dihydroterephthalic acid* of the structure,

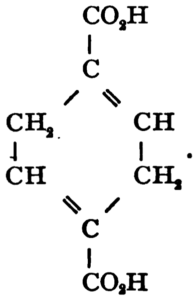


This acid occurs in both the "cis" and "trans" form, and has all of the characteristics of an unsaturated compound with two double unions.

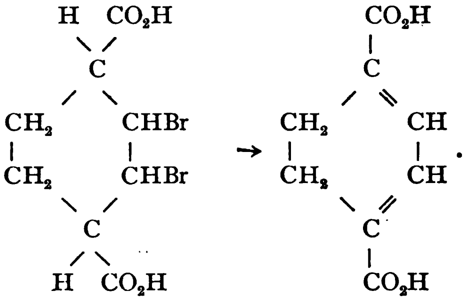
By boiling with caustic soda it is converted successively into the $\Delta^{1,5}$ acid,



and the $\Delta^{1.4}$ acid,

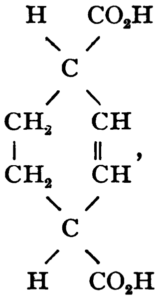


The $\Delta^{1.3}$ dihydro acid is formed by treating the dibromide of Δ^2 tetrahydroterephthalic acid with alcoholic potash:



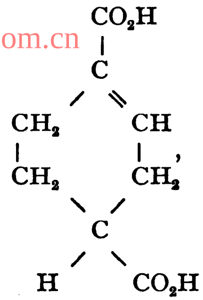
The three dihydroterephthalic acids last mentioned can show no "cis" and "trans" isomerism. (Why?)

The Δ^2 *tetrahydroterephthalic acid*,



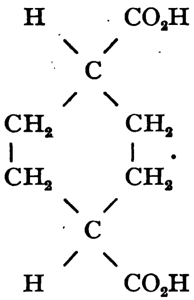
is obtained by reducing either the $\Delta^{1.3}$ or the $\Delta^{1.5}$ dihydroterephthalic acid. It exists in both the "cis" and "trans" forms.

By boiling with sodium hydroxide the last acid is converted into the Δ^1 *tetrahydroterephthalic acid*,



which can have but one stereomeric form.

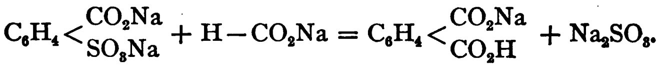
Further reduction of the last acid gives the "cis" and "trans" *hexa-hydroterephthalic acids*,



This gives the ten theoretically possible reduction products of terephthalic acid, and all of them have been prepared. In addition to these forms, several of the acids contain one or two asymmetric carbon atoms, and could, undoubtedly, be separated into optically active forms.

Use of the Phthalic Acids in Determining the Structure of Aromatic Compounds. — Phthalic acid, isophthalic acid, and terephthalic acid have been of great importance as compounds to which other compounds can be referred for the determination of their structure. The method which has been given (p. 105) for determining whether a given compound contains groups in the ortho, meta, or para position, while it is fundamental, is very tedious in its practical application. Having once determined the structure of a few benzene derivatives by that means, the structure of other compounds can usually be determined by a much shorter process.

To illustrate: One of the bibrombenzenes, $C_6H_4Br_2$, gives, on treatment with sodium and methyl iodide, a xylene, $C_6H_4<\begin{matrix}CH_3\\CH_3\end{matrix}$, which, on oxidation, yields terephthalic acid. The bibrombenzene was, therefore, a para compound. Again: One of the sulphobenzoic acids, $C_6H_4<\begin{matrix}CO_2H\\SO_3H\end{matrix}$, gives phthalic acid when its sodium salt is heated with sodium formate,



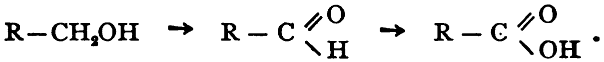
$$C_6H_4<\begin{matrix}CO_2Na\\SO_3Na\end{matrix} + H-CO_2Na = C_6H_4<\begin{matrix}CO_2Na\\CO_2H\end{matrix} + Na_2SO_3.$$

The same salt gives salicylic acid, $C_6H_4<\begin{matrix}CO_2H\\OH\end{matrix}$, when fused with caustic potash. Salicylic acid is, therefore, an ortho compound. It is to be remembered, however, that fusion with caustic potash often causes molecular rearrangements.

Many bibasic acids with relatively less hydrogen than those which have been considered are known. Many acids containing three, four, five, six and more carboxyl groups are also known. None of these would involve principles of sufficient novelty to justify their consideration here.

GENERAL METHODS OF PREPARING ACIDS.

1. Oxidation of primary alcohols and aldehydes.



$$R-CH_2OH \rightarrow R-C\begin{matrix}\diagup O\\ \diagdown H\end{matrix} \rightarrow R-C\begin{matrix}\diagup O\\ \diagdown OH\end{matrix}.$$

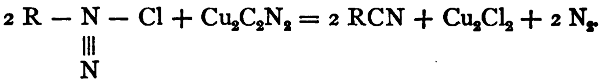
Alcohol. Aldehyde. Acid.

2. Oxidation of secondary alcohols and ketones with open chain, giving monobasic acids with a smaller number of carbon atoms; or of cyclic secondary alcohols and ketones, giving open-chain bibasic acids with the same number of carbon atoms.

3. Oxidation of hydrocarbons, either unsaturated hydrocarbons which break down at the point of double union, or aromatic hydrocarbons, whose side chains can be oxidized in such a manner that only the carbon atom attached to the benzene nucleus remains.

4. By distilling mixtures of the salts of alkyl esters of sulphuric acid, $R-O-SO_2-OH$, or of sulphonic acids, $R-SO_2OH$, with potassium cyanide, or by boiling aqueous or alcoholic solutions of primary, $R-CH_2-Br$, or secondary, $\begin{matrix}R\\R'\end{matrix}>CHBr$, halogen compounds,* with potassium cyanide, followed, in each case, by the saponification of the cyanide with an acid or alkali.

5. By treatment of a diazo compound of the benzene series with cuprous cyanide:



$$2\,R-\underset{\underset{N}{|||}}{N}-Cl + Cu_2C_2N_2 = 2\,RCN + Cu_2Cl_2 + 2\,N_2.$$

The cyanide must, of course, be subsequently saponified.

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* In a few instances tertiary halogen compounds have been used, but the yields are very poor.

6. By condensation of carbon dioxide, or carbonyl chloride, with an aromatic hydrocarbon by means of aluminium chloride:

$$C_6H_6 + \underset{\substack{\text{Carbonyl}\\ \text{chloride.}}}{COCl_2} + AlCl_3 = \underset{\text{Benzoyl chloride.}}{C_6H_5COCl} + AlCl_3 + HCl$$

$$C_6H_5COCl + H_2O = C_6H_5{-}CO_2H + HCl.$$

7. By condensing an aldehyde with the sodium salt of an acid in presence of the anhydride of the acid (Perkin's synthesis).

8. By condensing the sodium salt of malonic ester with a halogen compound (p. 252).

9. Unsaturated acids are prepared by method 7 above; by heating hydroxy acids; by treating monohalogen derivatives of the acids with caustic potash; and by reducing dihalogen derivatives in which the two halogen atoms are combined with adjacent carbon atoms.

10. Many organic acids occur free, or in the form of glycerides or other esters, in nature, and so may be obtained from various natural products.

Laboratory Exercises.

Preparation of the following compounds:

1. Formic acid.
2. Isobutyric acid.
3. Stearic acid.
4. Acrylic acid.
5. Benzoic acid from benzyl chloride: also from aniline.
6. Cinnamic acid.
7. Hydrocinnamic acid by reduction of cinnamic acid.
8. Oxalic acid.
9. Ethyl ester of malonic acid.
10. Hydrocinnamic acid from malonic ester and benzyl chloride.

11. Succinic acid.
12. Pimelic acid.
13. Camphoric acid; camphoric anhydride.
14. Phthalic acid; phthalic anhydride.
15. Phenol phthaleïn.
16. Terephthalic acid.

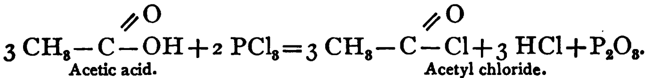
CHAPTER XIV.

DERIVATIVES OF ACIDS.

Only those derivatives in which the carboxyl is affected are characteristic of acids specifically, as distinguished from other substances, and only such derivatives will be considered in this chapter. Hydroxy and ketonic acids will be made the subject of the following chapter, while halogen derivatives, sulphonic acids and other substances which are to be considered as substitution products of the acids will be discussed along with other compounds containing the same substituting groups.

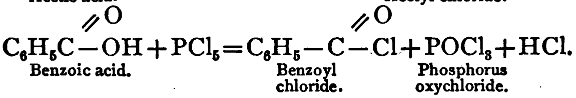
Acid Chlorides.

When acids are treated with phosphorus trichloride or phosphorus pentachloride, or when the salt of an acid is treated with phosphorus pentachloride, or phosphorus oxychloride, the chloride of an acid is formed. This contains one chlorine atom in place of one oxygen and one hydrogen atom, evidently in place of the hydroxyl group of the acid.



$$3\,CH_3-\overset{/\!/O}{C}-OH+2\,PCl_3=3\,CH_3-\overset{/\!/O}{C}-Cl+3\,HCl+P_2O_3.$$

Acetic acid. Acetyl chloride.



$$C_6H_5\overset{/\!/O}{C}-OH+PCl_5=C_6H_5-\overset{/\!/O}{C}-Cl+POCl_3+HCl.$$

Benzoic acid. Benzoyl chloride. Phosphorus oxychloride.

$$C_6H_5CO_2Na+PCl_5=C_6H_5COCl+POCl_3+NaCl.$$

$$2\,CH_3CO_2Na+POCl_3=2\,CH_3COCl+NaPO_3+NaCl.$$

The anhydrides of bibasic acids often give unsymmetrical chlorides when treated with phosphorus pentachloride (p. 262).

Acid fluorides, bromides, and iodides are also known, but have, relatively, very little importance.

The chlorides of the acids are mostly substances which can be distilled without decomposition, and have a penetrating, disagreeable odor. The boiling point is considerably lower than that of the acid from which the chloride is derived. Thus, acetic acid boils at 120°, acetyl chloride at 50.9°. Benzoic acid boils at 249°, benzoyl chloride at 195°.

The acid chlorides are decomposed by water with regeneration of the acid.

$$CH_3COCl + H_2O = CH_3CO_2H + HCl.$$

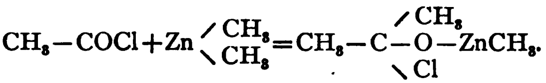
This decomposition takes place very easily with acetyl chloride and other chlorides of acids with low molecular weights, but much less quickly with benzoyl chloride and chlorides of acids of high molecular weight. In some cases when it is desired to regenerate an acid from the chloride of an acid which is itself liable to be decomposed by water (e.g., some brom acids) the decomposition can be effected with advantage by means of glacial formic acid.

$$R-COCl + H_2CO_2 = R-CO_2H + HCl + CO.$$

The chlorides of the acids are extremely reactive bodies, and are used in the preparation of anhydrides of the acids, esters and amides. (See below.)

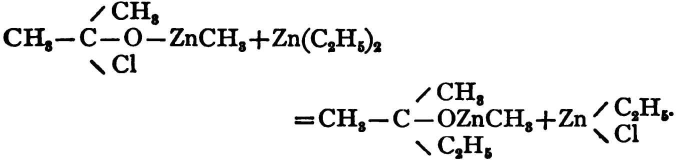
The chlorides of the acids are much more easily attacked by chlorine or bromine than are the free acids, and so are very often used in the preparation of halogen substitution products of the acids (p. 385).

When an acid chloride is mixed with a zinc alkyl, an addition product is formed:—

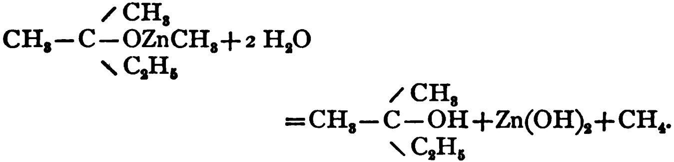


$$CH_3-COCl+Zn\begin{matrix}\diagup CH_3\\ \diagdown CH_3\end{matrix}=CH_3-\overset{\diagup CH_3}{\underset{\diagdown Cl}{C}}-O-ZnCH_3.$$

If this product is decomposed by water a ketone results (p. 217). If, on the other hand, it is allowed to stand for some weeks with the same or a different zinc alkyl and the product is then decomposed by water, a tertiary alcohol and a saturated hydrocarbon are formed.



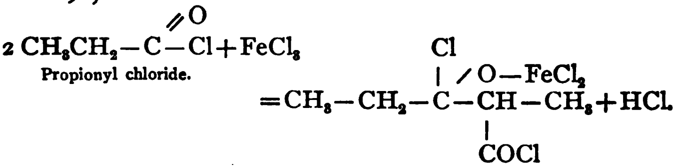
$$CH_3-\overset{\diagup CH_3}{\underset{\diagdown Cl}{C}}-O-ZnCH_3+Zn(C_2H_5)_2$$
$$=CH_3-\overset{\diagup CH_3}{\underset{\diagdown C_2H_5}{C}}-OZnCH_3+Zn\begin{matrix}\diagup C_2H_5.\\ \diagdown Cl\end{matrix}$$



$$CH_3-\overset{\diagup CH_3}{\underset{\diagdown C_2H_5}{C}}-OZnCH_3+2\,H_2O$$
$$=CH_3-\overset{\diagup CH_3}{\underset{\diagdown C_2H_5}{C}}-OH+Zn(OH)_2+CH_4.$$

2-Methylbutanol-2.

If chlorides of aliphatic acids are mixed with anhydrous ferric chloride, hydrochloric acid is evolved, and on decomposing the product of the reaction with water a ketone is formed. The first part of the reaction is doubtless similar to the syntheses by means of aluminium chloride (pp. 112 and 198).

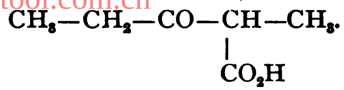


$$2\,CH_3CH_2-\overset{\diagup\!\!\diagup O}{C}-Cl+FeCl_3$$

Propionyl chloride.

$$=CH_3-CH_2-\overset{\overset{Cl}{|}\ \diagup O-FeCl_2}{C}-\underset{\underset{COCl}{|}}{CH}-CH_3+HCl.$$

The reaction product, on treatment with water, would give the acid,



$$CH_3-CH_2-CO-\underset{\displaystyle CO_2H}{\underset{|}{CH}}-CH_3.$$

This acid, as a β-ketonic acid (p. 351), would decompose into carbon dioxide and diethyl ketone,

$$CH_3CH_2-CO-CH_2CH_3.$$

Chlorides of acids may be reduced to aldehydes and alcohols.

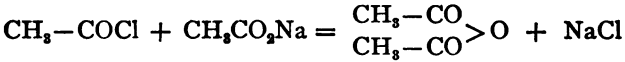
$$R-COCl \rightarrow R-COH \rightarrow R-CH_2OH.$$

Acetyl Chloride, $CH_3-\overset{\nearrow O}{C}-Cl$ (**ethanoyl chloride**), is prepared by treating glacial acetic acid with phosphorus trichloride (see above). It boils at 50.9°. It has a very disagreeable, penetrating odor and is a very important reagent in the organic laboratory.

Benzoyl Chloride, $C_6H_5C\begin{matrix}\nearrow O\\ \searrow Cl\end{matrix}$, is prepared by treating benzoic acid with phosphorus pentachloride. It is prepared technically, and was also first prepared (by Liebig and Wohler) by acting upon benzaldehyde, $C_6H_5\overset{\nearrow O}{C}-H$, with chlorine. Few, if any, other chlorides of acids have been prepared in this way. Benzoyl chloride boils at 195°. It is less easily decomposed by water than acetyl chloride.

ACID ANHYDRIDES.

When the chloride of an acid is warmed with the sodium salt of the acid, an anhydride is formed:



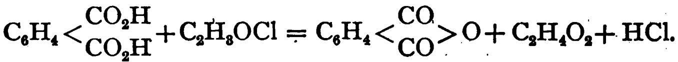
$$CH_3-COCl + CH_3CO_2Na = \begin{matrix}CH_3-CO\\ CH_3-CO\end{matrix}{>}O + NaCl$$

Acetic anhydride.

When monobasic acids of higher molecular weight are heated with acetic anhydride they are usually converted into anhydrides.

$$\underset{\text{Butyric acid.}}{2C_3H_7CO_2H} + (C_2H_3O)_2O = \underset{\text{Butyric anhydride.}}{(C_3H_7CO)_2O} + 2C_2H_4O_2$$

Bibasic acids in which the two carboxyl groups are separated by *two* or *three* carbon atoms form inner anhydrides on heating, or when warmed with acetic anhydride, acetyl chloride, phosphorus pentachloride, or phosphorus oxychloride.



$$\underset{\text{Phthalic acid.}}{C_6H_4<\begin{matrix}CO_2H\\CO_2H\end{matrix}} + \underset{\text{Acetyl chloride.}}{C_2H_3OCl} = \underset{\text{Phthalic anhydride.}}{C_6H_4<\begin{matrix}CO\\CO\end{matrix}>O} + C_2H_4O_2 + HCl.$$

Succinic acid and its derivatives form anhydrides more easily on heating than do glutaric acid and its derivatives.

The anhydrides of the acids decompose with water, and regenerate the acids from which they are derived, though less easily than the acid chlorides. The different anhydrides exhibit much the same differences as the chlorides in this respect. A few of the "inner" anhydrides are so stable that they may even be crystallized from water without decomposition.

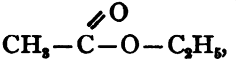
The anhydrides of the monobasic acids have a higher boiling point than the acids themselves. Acetic anhydride boils at 136.4°, benzoic anhydride boils above 400.°

With alcohols, ammonia and amines, anhydrides form esters and amides very much as acid chlorides do; but their action is much more mild.

Acetic Anhydride is by far the most important of the anhydrides of monobasic acids, and is extensively used as a reagent in organic laboratories for the preparation of esters and amides of acetic acid (usually called acetyl derivatives of the respective alcohols and amines) and in preparing the anhydrides of other acids.

Phthalic Anhydride and some of its more important derivatives have already been considered (p. 262).

ESTERS.

Esters are derivatives of acids in which the hydrogen of the carboxyl has been replaced by some hydrocarbon radical (an alkyl, alphyl, or aryl, p. 111) as C_2H_5, C_6H_5, etc. It is also often convenient to look upon them as alcohols in which the hydrogen of the hydroxyl has been replaced by an acid radical (an "acyl"). Thus, acetic ester may be considered as either *ethyl acetate*,  $CH_3-\overset{\overset{O}{/\!/}}{C}-O-C_2H_5$, or as the *acetyl derivative* of ethyl alcohol, $C_2H_5-O-C_2H_3O$.

In the earlier development of organic chemistry the esters were called "compound ethers," and such names as "acetic ether" and "benzoic ether" are still occasionally employed.

The esters are, in structure, salts of the acids, and it is often convenient to name them as such. There is this very important difference between salts and esters, however, that salts usually undergo a high degree of ionization in solution and so react almost instantaneously with other acids, bases or salts, while esters undergo only a very trifling ionization, and usually react slowly.

Preparation of Esters. — The more important methods for the preparation of esters are the following:

1. Action of an acid upon an alcohol.

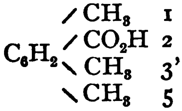
$$C_2H_5-OH + H_2SO_4 = \underset{\text{Ethyl sulphuric acid.}}{C_2H_5-HSO_4} + H_2O$$

$$C_2H_5-OH + CH_3CO_2H = \underset{\substack{\text{Ethyl ester of}\\\text{acetic acid.}}}{CH_3CO_2C_2H_5} + H_2O.$$

The reaction is a reversible one, and, if equimolecular proportions of an acid and alcohol are used, proceeds only till a state of equilibrium is reached, the amount of ester finally formed depending upon the nature of the alcohol and acid, and only to a limited degree upon the temperature. The *speed* of the reaction, on the contrary, is highly dependent on the temperature. The general rule which applies to all reactions where the rate is dependent on the temperature is that the rate doubles for each increase of ten degrees. In accordance with the law of mass action an increase in the amount of the acid will increase the amount of ester which can be obtained from a given amount of the alcohol, or an increase in the amount of the alcohol will increase the amount of the ester which can be obtained from a given weight of the acid. The most effective means for increasing the amount of the ester is to remove the water formed, and, in some cases, this can be practically accomplished.

As the progressive formation of the ester or its decomposition can be readily followed by the titration of the residual acid, the reaction has been extensively used in studying the laws of mass action. The laws governing the formation of esters with different classes of alcohols and acids have also been carefully studied, and many interesting facts discovered. The *rate* of esterification is much slower for secondary monobasic acids, $\left(\begin{matrix}R\\R'\end{matrix}{>}CH-CO_2H\right)$, than for primary, $(R-CH_2-CO_2H)$, and the rate is still slower for tertiary acids, $\left(\begin{matrix}R\diagdown\\R'-\\R''\diagup\end{matrix}C-CO_2H\right)$. Aromatic acids, in which the carboxyl is combined with the benzene nucleus, resemble, in general, the tertiary acids. The *limit* of esterification with equimolecular amounts of acid and alcohol varies between relatively narrow limits (67–76 per cent), being slightly higher for tertiary than for primary acids, which means, apparently, that the tertiary structure interferes relatively more with the decomposition of the ester by water than with its formation. With a given acid the rate of esterification is slower for a saturated secondary alcohol, $\left(\begin{matrix}R\\R\end{matrix}> CHOH\right)$, than for a primary alcohol, (RHC_2OH). The limit of esterification is also lower for the secondary than for the primary alcohol. For the tertiary alcohol the rate is still slower, and the limit is very low indeed (in general only about 5 per cent of the ester being formed).

V. Meyer's Law of Esterification.—In the aromatic series a very interesting law of esterification was discovered by Victor Meyer. In most cases aromatic acids are quite completely esterified on boiling for a few hours with methyl alcohol containing a little hydrochloric acid. If, however, the aromatic acid contains two groups in the ortho position with regard to the carboxyl of the acid, the esterification is almost entirely prevented. Thus, *mesitylene carboxylic acid*,



$$C_6H_2\begin{matrix}\diagup CH_3 & 1\\ \diagup CO_2H & 2\\ \diagdown CH_3 & 3\\ \diagdown CH_3 & 5\end{matrix}$$

gives, under the conditions mentioned, scarcely a trace of the ester. (*Ber. d. chem. Ges.* 27, 510, 1580, 3146; 29, 1397.)

The saponification of cyanides is also rendered very difficult by the presence of two groups ortho to the cyanogen group. Other effects of a similar nature have also been noticed.

2. By heating a mixture of an acid and alcohol with hydrochloric or sulphuric acid. The mixture is usually

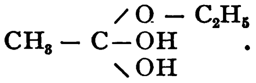
boiled with an upright condenser for some time, and, in general, only a small amount of the mineral acid (one to five per cent of the weight of the alcohol) is required. The reactions are the same as for the first method, the mineral acid remaining in the end unchanged. Its function is simply to hasten the reaction, and the laws which have been given as governing the reaction remain, in general, unchanged. It is commonly supposed that hydrochloric acid acts by the intermediate formation of an acid chloride.

$$CH_3CO_2H + HCl = CH_3COCl + H_2O$$
$$CH_3COCl + C_2H_5OH = CH_3CO_2C_2H_5 + HCl.$$

The sulphuric acid is supposed to form an alkyl sulphuric acid which then reacts with the acid to form the ester.

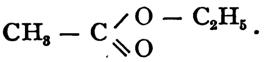
$$C_2H_5OH + H_2SO_4 = C_2H_5HSO_4 + H_2O$$
$$C_2H_5HSO_4 + CH_3CO_2H = CH_3CO_2C_2H_5 + H_2SO_4.$$

Another explanation is that the alcohol adds itself to the acid forming a compound of the formula,



$$CH_3 - C \begin{cases} O - C_2H_5 \\ -OH \\ OH \end{cases} .$$

This compound then loses water, and gives the ester,



$$CH_3 - C \begin{cases} O - C_2H_5 \\ O \end{cases} .$$

The acid, in some manner not clearly explained, but probably by the addition of its hydrogen ions to the oxygen of the acid, aids in forming the addition compound. The conduct of the aromatic acids coming under V. Meyer's law decidedly favors this view. These acids, which cannot be esterified by means of methyl alcohol and hydrochloric acid, can be readily converted into esters by first preparing from them the acid chloride or the silver salt (see below). It is difficult to explain this, if we suppose the function of the hydrochloric acid is to form the chloride of the acid, but if we suppose, instead, that the presence of the two ortho groups does not leave room for the ready formation of the addition compound, a satisfactory explanation is given. (V. Meyer, *Ber. d. chem. Ges.*, **27**, 510; **28**, 2773.)

It need scarcely be said that absolute alcohol is more suitable than ordinary alcohol for the preparation of esters by either the first or second method.

3. By treating an alcohol with an acid chloride or anhydride, or with an acid chloride or anhydride and sodium hydroxide.

$$C_6H_5COCl + C_2H_5OH = C_6H_5CO_2C_2H_5 + HCl$$

$$(C_2H_3CO)_2O + C_2H_5OH = CH_3CO_2C_2H_5 + C_2H_4O_2$$

$$C_6H_5COCl + C_6H_5OH + NaOH = \underset{\text{Phenyl benzoate.}}{C_6H_5CO_2C_6H_5} + NaCl + H_2O$$

$$(C_2H_3O)_2O + C_6H_5OH + NaOH = \underset{\text{Phenyl acetate.}}{C_2H_3O.OC_6H_5} + NaC_2H_3O_2 + H_2O.$$

The last two reactions are carried out in the presence of water, and are known as the "Schotten-Baumann" reaction. The acetyl and benzoyl derivatives of many substances containing alcoholic hydroxyl groups are crystalline bodies which can be easily purified, and so are admirably adapted for purposes of identification. The preparation of an acetyl or benzoyl derivative also serves in many cases to determine whether the oxygen of a given compound is in the form of hydroxyl or not, and, in other cases, to determine the number of hydroxyl groups present.

4. By treating the salt of an acid with an alkyl halide.

$$C_2H_4O_2 < \begin{matrix} CO_2Ag \\ CO_2Ag \end{matrix} + 2\,C_2H_5I = C_2H_4O_2 < \begin{matrix} CO_2C_2H_5 \\ CO_2C_2H_5 \end{matrix} + 2\,AgI.$$

Silver tartrate. Diethyl tartrate.

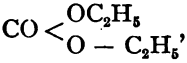
The silver salts and the alkyl iodides react, in general, most easily, but other salts and other halides are sometimes used.

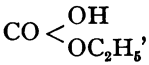
Saponification. — When esters are heated with water, acids or alkalies they are *saponified* or decomposed with the formation of the free acid, or a salt of the acid, and the alcohol. Reactions of this type have already been spoken of for the glycerides (p. 230), and the closely analogous reactions for cyanides have been repeatedly noticed. The ease of saponification varies very greatly. In general, it seems to correspond with the ease of formation of the ester, those esters which are easily formed being easily saponified. The strength of the acid, as measured by its dissociation constant, is also an important factor in determining the ease of saponification, esters of strong acids being more easily saponified than the esters of weak ones. Ethers and esters both have a structure in which two carbon atoms are united by means of oxygen, and, just as it is not easy to draw a satisfactory line of distinction between acids and alcohols, it is also difficult to define sharply the line between ethers and esters. If we should say that esters can be saponified by alkalies, while ethers cannot, the distinction would correspond nearly, though not exactly, with the distinction already drawn between acids and alcohols (p. 221. See also p. 143).

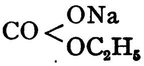
When the esters of derivatives of malonic acid are saponified by means of acids (hydrochloric or sulphuric acid) the acids formed are often decomposed at the same time with evolution of carbon dioxide. In a similar manner β-ketonic acids ($R-CO-CH_2CO_2H$) decompose when their esters are saponified with acids, and sometimes when saponified with alkalies, giving ketones (p. 351). In these, and other cases, it is evident that the esters are more stable than the acids from which they are derived, and esters can often be distilled with little or no decomposition when the corresponding acids decompose easily.

Just as methyl and ethyl ether boil at a lower temperature than methyl and ethyl alcohol, so the methyl and ethyl esters of acids boil at a lower temperature than the acids themselves. Ethyl acetate boils at 77°, ethyl benzoate at 211°.

Many of the esters of the acids and alcohols of the marsh-gas series have pleasant odors, and are extensively manufactured for use in the preparation of artificial fruit essences. *Isoamyl acetate* has the odor of pears, *octyl acetate* that of oranges, *ethyl butyrate* that of pineapples, and *isoamyl-isovalerate* that of oranges. A considerable number of esters are found in nature. The fats, which are esters of glycerol, have already been considered.

Diethyl Carbonate,  $CO<^{OC_2H_5}_{O-C_2H_5}$, is prepared by treating silver carbonate with ethyl iodide. It boils at 127°, and has a specific gravity of 0.9762 at $\frac{20°}{4°}$.

Monoethyl Carbonate,  $CO<^{OH}_{OC_2H_5}$, is not known in the free state. Its sodium salt is formed by passing carbon dioxide into a solution of sodium ethylate in absolute alcohol.



$$C_2H_5ONa + CO_2 = CO<^{ONa}_{OC_2H_5}$$

The free ester is probably formed when alcohol is left for a long time in contact with carbon dioxide under high pressure. The long continued effervescence of champagne is probably due to the slow decomposition of the ester into alcohol and carbon dioxide after the pressure is removed.

Orthocarbonic Ester,* $C(OC_2H_5)_4$, is prepared by treating chlorpicrin, CCl_3NO_2, with sodium ethylate.

$$CCl_3NO_2 + 4C_2H_5ONa = C(OC_2H_5)_4 + 3NaCl + NaNO_2.$$

The ester boils at 158°–159°.

Orthoformic Ester, $H-C(OC_2H_5)_3$, is prepared by treating chloroform with dry sodium ethylate, or by adding sodium to a mixture of chloroform, ethyl alcohol, and ether.

$$CHCl_3 + 3C_2H_5ONa = CH(OC_2H_5)_3 + 3NaCl.$$

Acetal, or Ethylidene Diethyl Ether, $CH_3-CH<\begin{matrix}OC_2H_5\\OC_2H_5\end{matrix}$, is formed by heating a mixture of acetaldehyde, $CH_3-\overset{\diagup H}{C}=O$, alcohol and acetic acid. It boils at 104°, and has a specific gravity of 0.8314 at $\frac{20^\circ}{4^\circ}$. It is soluble in 18 volumes of water at 25°. Acetal and similar compounds resemble the esters in their method of formation, but are more like the ethers in their properties. They are generally stable toward alkalies, but are easily decomposed into aldehyde and alcohol by acids. They are used in some reactions to advantage, in place of the less stable aldehydes.

The compounds which have been given illustrate the great stability of the esters in comparison with the free acids, and that, while two hydroxyl groups can seldom remain combined with the same carbon atom, derivatives of such compounds are known in large number.

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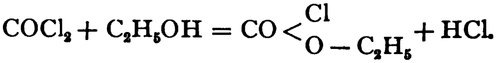
* The prefix "ortho" in this sense is applied in naming an acid derived from another by the addition of water, as orthophosphoric acid, H_3PO_4, from metaphosphoric acid, HPO_3. One molecule of water causes the formation of two hydroxyl groups.

Chlorformic Ester, or Chlorcarbonic Ester, $CO<^{Cl}_{OC_2H_5}$, is prepared by passing phosgene or carbonyl chloride into absolute alcohol.



$$COCl_2 + C_2H_5OH = CO<^{Cl}_{O-C_2H_5} + HCl.$$

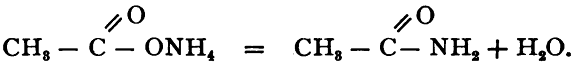
Chlorcarbonic ester boils at 93°. It has been used in the preparation of acids in a number of important syntheses.

These esters have been selected rather because of their somewhat unusual character than for other reasons. The number of esters known is, of course, very great, but a further account of individual esters seems to be unnecessary here.

AMIDES.

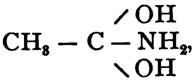
Amides are prepared:

1. By heating ammonium salts.



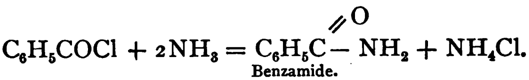
$$\underset{\text{Ammonium acetate.}}{CH_3-\overset{\text{//O}}{C}-ONH_4} = \underset{\text{Acetamide.}}{CH_3-\overset{\text{//O}}{C}-NH_2} + H_2O.$$

The reaction is probably to be interpreted as consisting at first in the dissociation of the salt into the free acid and ammonia, followed by the formation of the addition compound,



$CH_3-\underset{\diagdown OH}{\overset{\diagup OH}{C}}-NH_2$, and finally by the loss of water.

2. By treating the chloride of an acid with ammonia,



$$C_6H_5COCl + 2NH_3 = \underset{\text{Benzamide.}}{C_6H_5\overset{\text{//O}}{C}-NH_2} + NH_4Cl.$$

This method is especially suitable when the amide formed is insoluble or difficultly soluble in water.

3. By treating an ester with ammonia,

$$C_6H_5CO_2C_2H_5 + NH_3 = \underset{\text{Benzamide.}}{C_6H_5CONH_2} + C_2H_5OH.$$

4. By the partial saponification of cyanides or nitriles.

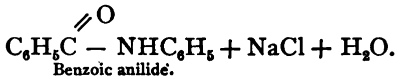
$$C_6H_5CN + H_2O + HCl \ = C_6H_5CONH_2 + HCl$$

or

$$C_6H_5CN + H_2O + KOH = C_6H_5CONH_2 + KOH.$$

5. Alkyl amides, $R-\overset{/\!\!/O}{C}-NHR$, are prepared by treating an acid chloride or anhydride with an amine and sodium hydroxide. (Schotten-Baumann's reaction, p. 282.)

$$C_6H_5-COCl + C_6H_5NH_2 + NaOH =$$



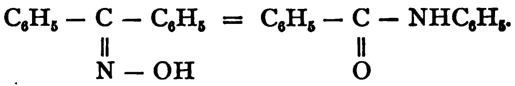
$$C_6H_5\overset{/\!\!/O}{C} - NHC_6H_5 + NaCl + H_2O.$$

Benzoic anilide.

$$(C_2H_3O)_2O + C_6H_5NH_2 + NaOH =$$

$$\underset{\text{Acetanilide.}}{C_6H_5NH(C_2H_3O)} + NaC_2H_3O_2 + H_2O.$$

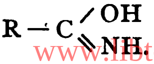
6. Alkyl amides are also formed by molecular rearrangement from the oximes of ketones, by treating them with phosphorus pentachloride. (Beckmann's rearrangement, p. 200.)

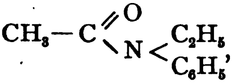


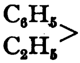
$$C_6H_5 - \underset{\substack{\| \\ N - OH}}{C} - C_6H_5 \ = \ C_6H_5 - \underset{\substack{\| \\ O}}{C} - NHC_6H_5.$$

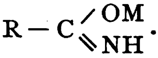
Oxime of benzophenone. Benzoic anilide.

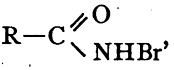
Structure of the Amides. — The structure of the amides follows from their formation from acid chlorides, and from cyanides, and from their saponification to acids. From these reactions it is evident that the nitrogen is combined with the end carbon atom, and does not lie between that carbon atom and the nucleus. The two formulae which would agree with these facts are, $R - C\genfrac{}{}{0pt}{}{/\!\!/O}{\backslash NH_2}$ and

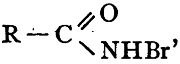

$\mathrm{R-C}\begin{array}{l}\diagup\mathrm{OH}\\ \diagdown\!\!\diagdown\mathrm{NH}.\end{array}$ The second formula would represent a substance with acid properties, and so does not agree well with the ordinary properties of the amides. Nor does it agree with the existence of such compounds as ethyl-acetanilide,

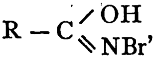

$\mathrm{CH_3-C}\begin{array}{l}\diagup\!\!\diagup\mathrm{O}\\ \diagdown\mathrm{N}<\begin{array}{l}\mathrm{C_2H_5}\\ \mathrm{C_6H_5}\end{array}\end{array}$, in which the ethyl group is known to be combined with the nitrogen by the fact that it yields ethyl aniline,

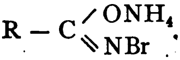

$\begin{array}{l}\mathrm{C_6H_5}\\ \mathrm{C_2H_5}\end{array}>\mathrm{NH}$, on saponification. The amides of strong acids do, however, form salts in which one hydrogen atom is replaced by a metal, and it is probable that these salts have the structure


$\mathrm{R-C}\begin{array}{l}\diagup\mathrm{OM}\\ \diagdown\!\!\diagdown\mathrm{NH}\end{array}$. The bromamides,

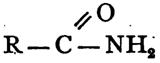

$\mathrm{R-C}\begin{array}{l}\diagup\!\!\diagup\mathrm{O}\\ \diagdown\mathrm{NHBr}\end{array}$, combine with ammonia in an ethereal solution to form salts, while in a solution in benzene they do not do this. This is most readily explained by supposing that in the free state these amides have the structure,

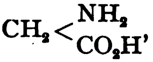

$\mathrm{R-C}\begin{array}{l}\diagup\!\!\diagup\mathrm{O}\\ \diagdown\mathrm{NHBr}\end{array}$, but that in an ethereal solution this readily passes over into the tautomeric (see p. 297) form,


$\mathrm{R-C}\begin{array}{l}\diagup\mathrm{OH}\\ \diagdown\!\!\diagdown\mathrm{NBr}\end{array}$, which would form with ammonia the salt

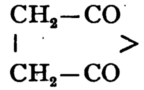
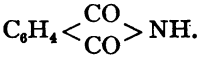
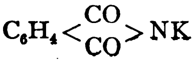

$\mathrm{R-C}\begin{array}{l}\diagup\mathrm{ONH_4}\\ \diagdown\!\!\diagdown\mathrm{NBr}\end{array}$. Compounds of this type are called "pseudo" acids, as in the free state they are not acids at all. (Auwers, *Ber. d. chem. Ges.* 35, 228.)

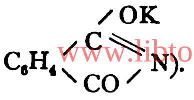
Assuming the formula


$\mathrm{R-\overset{\diagup\!\!\diagup O}{C}-NH_2}$ as representing the ordinary structure of the *amides*, they may be considered either as acids, in which the hydroxyl of the carboxyl group has been replaced by the *amido* (NH_2) group, or as ammonia

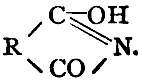
in which one hydrogen atom has been replaced by an acid radical (an acyl group). The *amines*, on the other hand, are to be defined as alcohols in which the hydroxyl group is replaced by the *amino* group (NH_2), or as ammonia in which one or more hydrogen atoms have been replaced by hydrocarbon radicals (alkyl groups). Unfortunately, the distinction here made between the prefixes *amido* and *amino* is not always followed in the literature. Thus glycocoll,  $CH_2<^{NH_2}_{CO_2H}$, should, in accordance with this distinction, be called aminoacetic acid, since the NH_2 group is to be considered as replacing alcoholic and not acid hydroxyl, or it is to be considered as combined with the hydrocarbon radical. It is often called, however, amidoacetic acid. The more logical nomenclature is now used by many careful writers.

In a few cases two hydrogen atoms in ammonia have been replaced by acid groups, giving compounds of the type represented by diacetamide, $NH(C_2H_3O)_2$. Such compounds are comparatively rare and unimportant. Triacetamide, $N(C_2H_3O)_3$, has also been prepared.

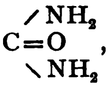
Those bibasic acids in which the carboxyl groups are so situated as to form inner anhydrides (p. 254), form *imides* in which the connecting oxygen of the anhydride is replaced by the imido (NH) group. Thus, succinic acid gives *succinimide*,  $\begin{array}{l}CH_2-CO\\ \vert \qquad\qquad >NH\\ CH_2-CO\end{array}$, and phthalic acid gives phthalimide,  $C_6H_4<^{CO}_{CO}>NH$. The hydrogen of the imide group is sufficiently acid to be replaced by metals with the formation of well-defined salts, as, for instance, *potassium phthalimide*,  $C_6H_4<^{CO}_{CO}>NK$ (or, possibly,



The imides are, in general, such weak acids, however, that their salts are decomposed by carbonic acid. It is noticeable that the derivatives of ammonia exhibit all gradations from the aliphatic amines (as CH_3NH_2), which are strong bases in aqueous solutions and combine with acids to form stable ammonium salts, to the imides, some of which are comparatively strong acids. As acids it is possible, or probable, however, that the imides react in the tautomeric form,



Urea, or Carbamide,



$$C{=}O\begin{matrix}\diagup NH_2\\ \\ \diagdown NH_2\end{matrix}$$

, is the amide of carbonic acid. It is of especial interest because it is to be looked upon as the final oxidation product of the proteïns, and is the form in which most of the nitrogen of the food eaten leaves the human body. It is, further, of great historical interest as being the first "organic" compound prepared synthetically. In 1828 Wöhler discovered its formation when a solution of ammonium cyanate, $NH_4-N=C=O$, is evaporated. The synthesis was the first step toward the overthrow of the view that compounds are formed in living bodies under the influence of a peculiar "vital force." It was the beginning of a long series of syntheses which have led to the conviction that the chemical and physical laws all apply equally to living and to dead matter, and that, while many of the processes which go on in living bodies cannot be imitated in our laboratories, there is no essential difference in character between laboratory syntheses and syntheses effected in living bodies. No reference is made here, of course, to the formation of *organized structure*, which is, apparently, something quite distinct from the formation of chemical compounds.

The transformation is a reversible one, and its study has furnished an interesting confirmation of the laws which govern reversible "mass" reactions. Walker and Hambly, *J. Chem. Soc.* 67, 751; Walker and Kay, *Ibid*, 71, 489.

In addition to its preparation from ammonium cyanate, urea can be prepared by treating carbonyl chloride, $COCl_2$, with ammonia, by heating ammonium carbamate, $CO<\begin{matrix}NH_2\\ONH_4\end{matrix}$, and by treating diethyl carbonate, $CO<\begin{matrix}OC_2H_5\\OC_2H_5\end{matrix}$, with ammonia. It will be noticed that these are simply applications of the first three general methods of preparing amides.

Urea crystallizes from water, or from ethyl or amyl alcohol, in long prisms. It melts at 132°, and is easily soluble in water and in alcohol.

Urea acts as a weak, monacic base. Urea nitrate, $CON_2H_4.HNO_3$, is difficultly soluble in water, and is used in the separation of urea from urine.

Urea also forms double salts with many inorganic salts. $NaCl.CON_2H_4$ and $Hg(NO_3)_2.4CON_2H_4$ may be taken as types of these. A compound of especial interest is the one with mercuric nitrate and mercuric oxide,

$$Hg(NO_3)_2(CON_2H_4)_2.3HgO.$$

This is formed on adding a dilute solution of mercuric nitrate to a solution containing urea, and is made use of for purposes of quantitative determination (Liebig).

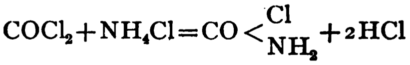
Urea is decomposed with evolution of nitrogen by a solution of sodium hypobromite.

$$CO(NH_2)_2+3NaBrO=CO_2+N_2+2H_2O+3NaBr.$$

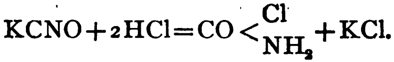
This reaction is also used for the quantitative determination [illegible] urea.

Carbamic Acid, $CO<{OH \atop NH_2}$, is not known in the free state. Its ammonium salt, *ammonium carbamate*, $CO<{ONH_4 \atop NH_2}$, is formed when ammonia and carbon dioxide are brought together, and is a constituent of commercial ammonium carbonate. A freshly prepared solution of the ammonium salt gives no precipitate with calcium chloride, but, in solution, the salt gradually takes up water and changes to ammonium carbonate.

Carbamic Chloride (urea chloride), $CO<{Cl \atop NH_2}$, is formed by passing phosgene (carbonyl chloride), $COCl_2$, over ammonium chloride at 400°. It is also formed by the action of hydrochloric acid gas on potassium cyanate.



$$COCl_2+NH_4Cl=CO<{Cl \atop NH_2}+2HCl$$

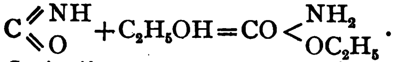


$$KCNO+2HCl=CO<{Cl \atop NH_2}+KCl.$$

Carbamic chloride is sometimes used in the synthesis of aromatic amides by Friedel and Crafts reaction. It has the advantage over carbonyl chloride, for the synthesis of acids, in that the amide group prevents the formation of ketones (p. 199). Derivatives of carbamic chloride, as phenyl carbamic chloride, $CO<{Cl \atop NHC_6H_5}$, are sometimes used for a similar purpose.

Urethane, or the Ethyl Ester of Carbamic Acid, is prepared from chlorcarbonic ester and ammonia, or from cyanic acid and alcohol.

$$CO<\begin{matrix}Cl\\OC_2H_5\end{matrix}+2NH_3=CO<\begin{matrix}NH_2\\OC_2H_5\end{matrix}+NH_4Cl$$

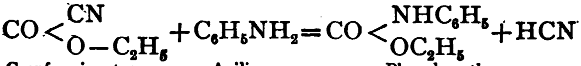


$$C\begin{matrix}/\!/NH\\ \backslash\!\backslash O\end{matrix}+C_2H_5OH=CO<\begin{matrix}NH_2\\OC_2H_5\end{matrix}.$$

Cyanic acid. Urethane.

Urethane crystallizes in leaflets which melt at 50°. It boils at 180°.

Phenyl Urethane is formed when cyanformic ester is heated with aniline.



$$CO<\begin{matrix}CN\\O-C_2H_5\end{matrix}+C_6H_5NH_2=CO<\begin{matrix}NHC_6H_5\\OC_2H_5\end{matrix}+HCN$$

Cyanformic ester. Aniline. Phenyl urethane.

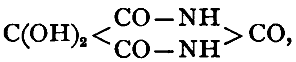
Phenyl urethane melts at 52° and boils at 238°. It crystallizes in needles.

Uric Acid, $C_5H_4N_4O_3$, is to be considered as a derivative of urea. It was discovered by Scheele in 1776. The foundation for a knowledge of the relations of the body to other substances was laid by the classical research of Wöhler and Liebig (*Ann. d. Chem.* (Liebig), **26**, 241 (1838)). The present view of the structure of the body is based on the work of many different chemists, among whom may be mentioned especially Wöhler, Liebig, Baeyer, Emil Fischer, Strecker, Medicus, and Behrend and Roosen. No attempt at a historical discussion of the development of knowledge of the body will be made, though such a discussion is of great interest, and would carry with it an epitome of the changing theories with regard to organic compounds. The interest of Wöhler and Liebig in the body was doubtless occasioned by its occurrence in animal substances, and the important relation which it evidently bears to physiological processes.

Alloxan. — When uric acid is oxidized with nitric acid, it gives *alloxan*, $C_4H_2N_2O_4$.

$$C_5H_4N_4O_3 + 4O = C_4H_2N_2O_4 + CO_2 + N_2 + H_2O.$$

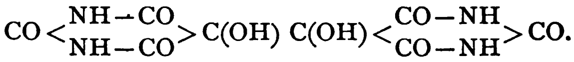
Alloxan crystallizes from water in long rhombic prisms, of the triclinic system. These contain four molecules of water, of which three molecules escape in dry air, while the fourth molecule is expelled at 150°. By boiling with alkalies it is decomposed into urea and mesoxalic acid, $CO<\begin{matrix}CO\,OH\\CO\,OH\end{matrix}$. This, together with the fact that alloxan is not an acid, establishes for it the formula $CO<\begin{matrix}CO-NH\\CO-NH\end{matrix}>CO$. The form with one molecule of water undoubtedly is



$$C(OH)_2<\begin{matrix}CO-NH\\CO-NH\end{matrix}>CO,$$

the presence of the negative groups giving relative stability to a compound having two hydroxyl groups combined with a single carbon atom.

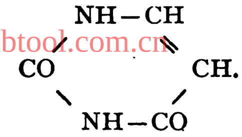
Alloxantin, $C_8H_6N_4O_8 + 2H_2O$, is formed by the reduction of alloxan, and is to be considered as the *pinacone* (p. 188) of alloxan, having the structure,



$$CO<\begin{matrix}NH-CO\\NH-CO\end{matrix}>C(OH)\;C(OH)<\begin{matrix}CO-NH\\CO-NH\end{matrix}>CO.$$

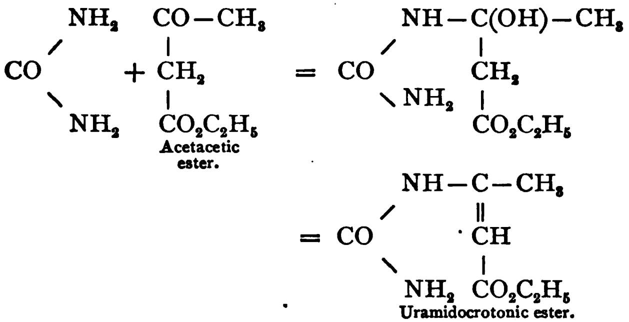
Parabanic Acid, $CO<\begin{matrix}NH-CO\\ \qquad|\\NH-CO\end{matrix}$, is formed by the further oxidation of alloxan and by the oxidation of uric acid. Its structure is established by its decomposition by alkalies, which gives urea and oxalic acid.

Structure of Uric Acid. — The series of syntheses which most clearly establishes the formula for uric acid depends on the formation of substances derived from *uracil*,



The mother substance, uracil itself, has not been prepared.

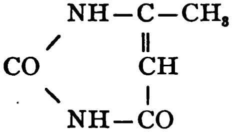
Acetacetic ester combines with urea to form *uramido crotonic ester*.



Acetacetic ester.

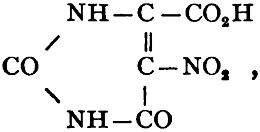
Uramidocrotonic ester.

When the last compound is saponified with an alkali, and the resulting salt is treated with an acid, *methyl-uracil*,



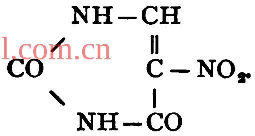
, is formed.

Methyl uracil, on treatment with concentrated nitric acid, gives *nitrouracil-carboxylic acid*,

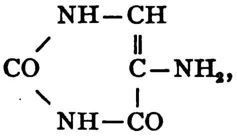


,

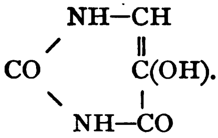
and this loses carbon dioxide, when its aqueous solution is boiled, and forms nitrouracil,



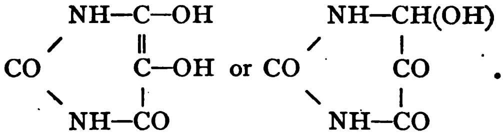
This, by reduction with tin and hydrochloric acid, yields partly *aminouracil*,



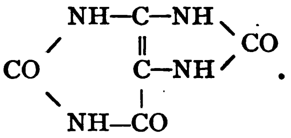
and partly, with an elimination of the nitro group, *oxyuracil* (*isobarbituric acid*),



Oxyuracil gives, by oxidation with bromine water, *dioxyuracil* (*isodialuric acid*),

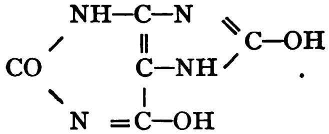


Dioxyuracil when warmed with urea, $CO<^{NH_2}_{NH_2}$, and concentrated sulphuric acid, is converted into *uric acid*,

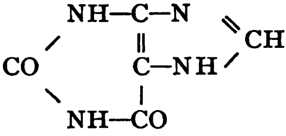
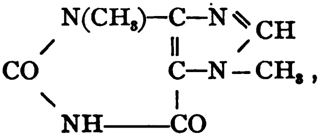
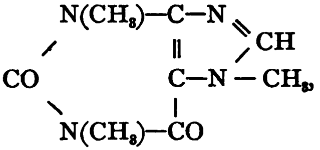


The relation between uric acid and alloxan, and the importance of alloxan in the work which has led to a knowledge of the structure of uric acid, is apparent from the formula last given.

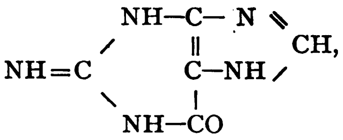
Uric acid is a bibasic acid, forming both acid and normal salts, of which the sodium salts, $NaC_5H_3N_4O_3+\frac{1}{2}H_2O$ and $Na_2C_5H_2N_4O_3+H_2O$, may be taken as types. In these salts it is evidently the hydrogen of the imido (NH) groups which is replaced, unless, as is possible, the salts are derived from the *tautomeric* form



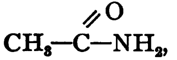
Tautomeric Compounds. — The word *tautomer* was originally used by Laar (*Ber. d. chem. Ges.*, 18, 648 (1885)) to designate a class of bodies which react sometimes as though of one structure, and at other times as though of another. Laar's thought seems to have been that such substances possess, in some sense, *both* structures. Since, in a number of cases, both forms of bodies of this class have been prepared, Laar's original interpretation of the phenomenon is no longer tenable. At most we can only suppose that in some cases both forms are present, and that each form passes readily into the other. Since the words tautomer and tautomerism are more often used, and are more familiar than any others for the designation of this class of bodies, it seems desirable to retain them. The term will always be employed in this book with the understanding that a tautomeric body may exist in two forms which are structurally different. In some cases it is extremely difficult to decide whether the common form of the body has the one or the other structure, or whether, perhaps, it is a mixture of the two forms. In other cases, both forms have been isolated and their structure clearly established. In most cases tautomeric bodies are capable of existing in a ketone form (R—CO—CH_2—) and an "enol" (unsaturated alcoholic) (R—C(OH)=CH—) form.

Xanthine,  , **Dimethylxanthine, or Theobromine,**  , **and Trimethylxanthine, or Caffeïne, or Theïne,**  are closely related to uric acid in structure, but differ from it very decidedly in their properties. While xanthine retains enough of the acid properties of uric acid to dissolve readily in a solution of potassium hydroxide, it is precipitated from such a solution by carbon dioxide, and it combines with hydrochloric acid and strong mineral acids to form salts, of which the chloride, $C_5H_4N_4O_2HCl$, may be taken as a type. It is evident that the hydrogen of the NH which is between the two carbonyl groups gives to xanthine its very slight acid properties, while the NH combined with the CH gives the weak basic properties. Theobromine and caffeïne are somewhat stronger bases. Caffeïne combines with two molecules of hydrochloric acid, but only the salt with one molecule of the acid is fairly stable.

Xanthine is found in minute amount in the urine. Theobromine is found in cacao; caffeïne is found in cacao, coffee, and tea. In large doses caffeïne is a poison, but its effects can be overcome by artificial respiration. Xanthine, theobromine, and caffeïne are classed as *alkaloids*, that is, as organic bases which are found in nature. Each has been prepared synthetically.

Guanine,  , is found in guano.

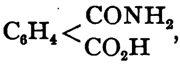
It is converted, by nitrous acid, into xanthine, the NH group being replaced by oxygen.

Acetamide, 

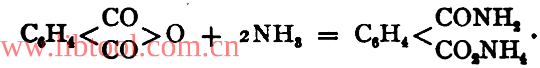
$CH_3{-}\overset{\displaystyle /\!\!/O}{C}{-}NH_2$, is prepared by heating ammonium acetate for several hours at 220°–230° in a sealed tube, and distilling the mixture of water, ammonium acetate, and acetamide which results. Acetamide crystallizes in colorless, odorless, rhombohedral crystals which melt at 82° and boil at 222°. It can be crystallized from benzene, in which it is difficultly soluble. It is very easily soluble in water and in alcohol.

Acetamide is easily saponified to acetic acid and ammonia by alkalies, or even by boiling with water. Warming with phosphorus pentoxide converts it into *methyl cyanide* or *acetonitrile*, CH_3CN.

Benzamide, $C_6H_5CONH_2$, is easily prepared by treating benzoyl chloride with aqueous ammonia. Benzamide crystallizes in leaflets which melt at 128°. It is difficultly soluble in water, easily soluble in alcohol.

Phthalamidic Acid, 

$C_6H_4<\begin{array}{l}CONH_2\\CO_2H\end{array}$, is formed when phthalic anhydride is dissolved in aqueous ammonia.



$$C_6H_4{<}\begin{matrix}CO\\CO\end{matrix}{>}O + 2NH_3 = C_6H_4{<}\begin{matrix}CONH_2\\CO_2NH_4\end{matrix}.$$

CYANIDES OR NITRILES.

The cyanides have been so often referred to that they will require only a short notice here. They are prepared:

1. By distilling a mixture of a salt of an acid ester of sulphuric acid, a salt of a sulphonic acid, or a halogen compound, with potassium cyanide.

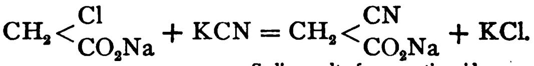
$$\underset{\text{Ethyl sulphuric acid.}}{C_2H_5KSO_4} + KCN = \underset{\text{Ethyl cyanide (Propiontirile).}}{CH_3CH_2CN} + K_2SO_4$$

$$C_6H_5SO_3K + KCN = C_6H_5CN + K_2SO_3.$$

This method can only be applied, of course, when the cyanide can be distilled without decomposition.

2. By boiling a halogen compound with potassium cyanide in an aqueous or alcoholic solution.

$$C_2H_5Br + KCN = \underset{\text{Ethyl cyanide.}}{C_2H_5CN} + KBr$$



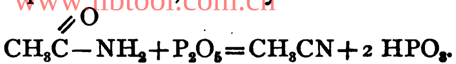
$$CH_2{<}\begin{matrix}Cl\\CO_2Na\end{matrix} + KCN = CH_2{<}\begin{matrix}CN\\CO_2Na\end{matrix} + KCl.$$

Sodium salt of cyanacetic acid.

The reaction takes place readily only with primary $(R-CH_2X)$ or secondary $\left(\begin{matrix}R\\R\end{matrix}{>}CHX\right)$ halogen compounds. Aromatic compounds in which the halogen is combined with the nucleus $\left(\text{as in } C_6H_5Br \text{ or } C_6H_4{<}\begin{matrix}CH_3\\Br\end{matrix}\right)$ will not react in this manner, but if the halogen is in the side chain the cyanide can be readily obtained. Thus:

$$\underset{\text{Benzyl chloride.}}{C_6H_5CH_2Cl} + KCN = \underset{\text{Benzyl cyanide.}}{C_6H_5CH_2CN} + KCl.$$

3. By treatment of amides with phosphorus pentoxide, phosphorus pentachloride, or acetyl chloride.



$$CH_3\overset{\displaystyle /\!\!/ O}{C}-NH_2+P_2O_5=CH_3CN+2\,HPO_3.$$

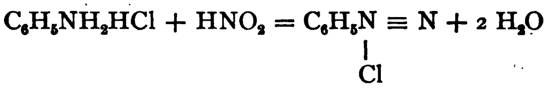
Acetamide. Methyl cyanide.

4. From isocyanides by rearrangement.

$$C_6H_5N=C \rightarrow C_6H_5-C\equiv N.$$

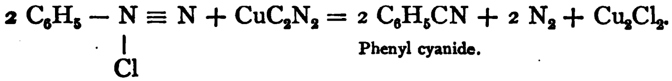
Phenyl isocyanide. Phenyl cyanide.

5. From aromatic amines through the diazo compound (p. 461) with the use of cuprous cyanide. (Sandmeyer's reaction.)



$$C_6H_5NH_2HCl + HNO_2 = C_6H_5\underset{\displaystyle Cl}{\underset{|}{N}} \equiv N + 2\,H_2O$$

Aniline chloride. Benzene diazonium chloride.



$$2\,C_6H_5 - \underset{\displaystyle Cl}{\underset{|}{N}} \equiv N + CuC_2N_2 = 2\,C_6H_5CN + 2\,N_2 + Cu_2Cl_2.$$

Phenyl cyanide.

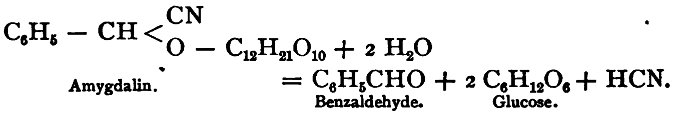
The structure of the cyanides is usually written $R-C\equiv N$. The practically important feature of this formula is that the carbon of the cyanogen group is represented as combined directly with the hydrocarbon radical. This is demonstrated by the formation of the cyanides from the amides, by the ready saponification of cyanides to amides and acids, and by their reduction to amines (p. 422).

The cyanides furnish a ready means of passing from primary and secondary alcohols, and from aromatic amines, to acids containing one more carbon atom, and for this reason are of very great practical importance. Because of this double relationship to the alcohol radical on the one hand, and to the acid on the other, they are called either *cyanides or nitriles*. Thus, CH_3CN is called either *methyl cyanide* or *acetonitrile*.

The simple cyanides of not too high molecular weight are volatile, comparatively stable liquids which distill without decomposition. The cyanogen group has the same effect on an adjacent methylene (CH_2) group as has the carboxethyl group, for synthetical purposes (pp. 252 and 350).

Hydrocyanic Acid, HCN, may be considered in some sense as the nitrile of formic acid, $H-CO_2H$, and as such may be converted into formic acid by acids or alkalies. It also reacts, however, as an isocyanide, $H-N=C$ (see below), and it is uncertain whether free hydrocyanic has the one or the other structure, or whether, possibly, it may not be a mixture of the two tautomeric forms (p. 297).

Hydrocyanic acid is found in nature, in combination with benzaldehyde and glucose, in *amygdalin*, a bitter principle found in bitter almonds, peach stones, the leaves of the cherry and laurel, and in a number of other plants. When amygdalin is acted upon by the soluble ferment or enzyme, *emulsin*, it is decomposed.



$$\underset{\text{Amygdalin.}}{C_6H_5-CH{<}^{CN}_{O-C_{12}H_{21}O_{10}}} + 2\,H_2O = \underset{\text{Benzaldehyde.}}{C_6H_5CHO} + 2\,\underset{\text{Glucose.}}{C_6H_{12}O_6} + HCN.$$

Pure hydrocyanic acid (prussic acid) is a volatile liquid which boils at 26.1°. It is a very violent poison. If moist, or in solution, it decomposes rapidly with the formation of brown amorphous substances. A trace of a mineral acid makes the solution more stable. Hydrocyanic acid is a much weaker acid than carbonic acid, though a stronger acid than phenol (p. 144).

Potassium cyanide, KCN, is formed when nitrogen is passed over a heated mixture of potassium carbonate and carbon, apparently by the direct union of the three elements of which it is composed. Potassium ferrocyanide, $K_4FeC_6N_6 + 3H_2O$, which is still the chief commercial source of potassium cyanide and related compounds, is prepared by heating refuse nitrogenous organic matter, as blood, bone, leather scraps, etc., with potassium carbonate and iron turnings. A certain amount of cyanogen compounds are also recovered as a by product in the manufacture of illuminating gas. Potassium cyanide, or rather a mixture of potassium and sodium cyanides, is now made by heating the ferrocyanide with metallic sodium.

$$K_4FeC_6N_6 + 2\,Na = 4\,KCN + 2\,NaCN + Fe.$$

The ferrocyanide is extensively used in making Prussian blue, and potassium cyanide is employed on a large scale in extracting gold from its ores.

In the complex cyanides, of which potassium ferrocyanide, potassium ferricyanide, $K_3FeC_6N_6$, and potassium silver cyanide, $KAgC_2N_2$, may be taken as types, the heavy metal combines with the cyanogen to form very stable groups which become the negative ion in solution. This can be demonstrated, experimentally, by the fact that the iron or silver of such solutions wanders toward the positive pole during electrolysis, and also by the fact that in such solutions iron or silver ions cannot be detected by the usual reactions. The formation of these complex ions is generally supposed to be due to a polymerization of the cyanogen group, but there can scarcely be said to be much positive evidence to support that view.

Cyanogen Chloride, $CNCl$, is formed by the action of chlorine on hydrocyanic acid.

$$HCN + Cl_2 = CNCl + HCl.$$

It is a volatile liquid which boils at 15.5°. It polymerizes easily, giving *cyanuric* chloride, $C_3N_3Cl_3$, which melts at 145° and boils at 190°.

Cyanogen chloride gives, with ammonia, cyanamide, $C\equiv N-NH_2$, or, more probably, $H-N=C=NH$.

ISOCYANIDES OR ISONITRILES.

The isocyanides are prepared:—

1. By heating alkyl iodides with silver cyanide.

$$C_2H_5I+AgNC=C_2H_5NC+AgI.$$

Ethyl isocyanide.

2. By treating a primary amine with chloroform and caustic potash.

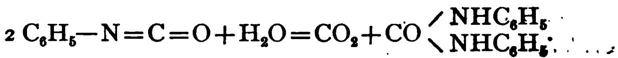
$$C_6H_5NH_2+CHCl_3+3\ KOH=C_6H_5NC+3\ KCl+3\ H_2O.$$

Aniline. Phenyl isocyanide.

Isocyanides are also formed in small amount in the various methods of preparing cyanides.

The isocyanides are generally liquids which boil at a lower temperature than the cyanides. They are violent poisons, and have an exceedingly disagreeable odor.

The isocyanides combine with two atoms of chlorine or bromine to form compounds of which *phenylisocyanide chloride*, $C_6H_5NCCl_2$, is a type. This, on treatment with silver oxide, is oxidized to *phenyl carbonimide*, or *phenyl isocyanate*, $C_6H_5N=C=O$. Phenyl carbonimide is decomposed by water into carbon dioxide and carbanilide or diphenyl urea:

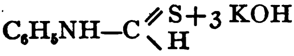


$$2\ C_6H_5-N=C=O+H_2O=CO_2+CO\begin{matrix}\diagup NHC_6H_5\\ \diagdown NHC_6H_5\end{matrix}.$$

Phenyl isocyanate or phenyl carbonimide. Diphenyl urea.

Phenyl isocyanide also combines with hydrochloric acid to form the compound, $2\ C_6H_5NC\,.\,3\ HCl$. On account of this property of combining directly with halogen acids, the isocyanides were formerly called "*carbylamines*," but the resulting compounds are decomposed by water, and do not comport themselves at all as ordinary salts.

Phenyl isocyanide combines directly with sulphur to form phenyl isothiocyanate (phenyl mustard oil), $C_6H_5N = C = S$, and with hydrogen sulphide to form phenylthioformamide,* or thioformanilide, $C_6H_5—NH—C\genfrac{}{}{0pt}{}{/\!\!/ S}{\diagdown H}$. This thioformanilide is decomposed by caustic potash, giving aniline, potassium sulphide, and potassium formate.



$$C_6H_5NH—C\genfrac{}{}{0pt}{}{/\!\!/ S}{\diagdown H}+3\,KOH$$
$$=C_6H_5NH_2+K_2S+HCO_2K+H_2O.$$

The reactions which have been given to illustrate the chemical conduct of the isocyanides can only be satisfactorily explained by supposing that the nitrogen in them is combined with the hydrocarbon radical. The isomerism of the cyanides and isocyanides is evidently due to the combination of the radical with the carbon of the cyanogen in the former, and with the nitrogen in the latter.

Phenyl cyanide is C_6H_5CN.
Phenyl isocyanide is C_6H_5NC.

For practical purposes these formulae answer almost all requirements. In further detail the formula of the cyanide is usually written $C_6H_5 - C \equiv N$. The formula for the isocyanide has often been written $C_6H_5N \equiv C$. The direct combination with chlorine, bromine, sulphur, and hydrogen sulphide, the decomposition products of the resulting compounds, and especially the formation of phenyl carbonimide, can be better explained by the formula, $C_6H_5 - N = C$. This formula represents the carbon as bivalent in the isocyanides.

The formation of isocyanides from silver cyanide seems to

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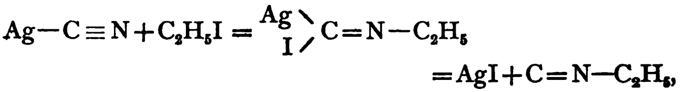
* The student should notice the composition of these names, and explain them.

indicate that this compound has the formula, $Ag-N=C$, but the difficulty of determining whether the reaction in such cases is originally an addition or a substitution leaves the structure in doubt. The two reactions,

$$Ag-N=C+C_2H_5I = C_2H_5N=C+AgI,$$

and



$$Ag-C\equiv N+C_2H_5I = \begin{array}{l}Ag\diagdown\\ I\diagup\end{array}C=N-C_2H_5 \\ =AgI+C=N-C_2H_5,$$

give the same final result, while the structures assigned to the silver cyanide are different. The difficulty met with here is characteristic of tautomeric substances, and illustrates the chief reason why the study of such compounds has been a very fruitful source of controversy. Since potassium cyanide gives ethyl cyanide, and not the isocyanide, when treated with ethyl iodide, it follows that either the structures of silver cyanide and potassium cyanide are different (e.g., $Ag-N=C$ and $K-C\equiv N$), or that the reaction is in one case a substitution and in the other case an addition.

CYANATES AND ISOCYANATES.

When potassium cyanide is heated with lead oxide, or when *dry* potassium ferrocyanide is heated with potassium pyrochromate, potassium cyanate, KCNO, is formed. If we assume the formula $K-N=C$ for potassium cyanide, potassium cyanate is probably $K-N=C=O$. This formula also agrees best with the transformation of ammonium cyanate to urea (p. 290), but the demonstration of the formula meets with the same difficulty which attends the study of the cyanides (see above).

Ethyl Cyanate, $C_2H_5-O-C\equiv N$, is formed when cyanogen chloride is passed into a solution of sodium ethylate,

$$C_2H_5ONa + CNCl = C_2H_5{-}O{-}C{\equiv}N + NaCl.$$

Ethyl cyanate is decomposed by alkalies into ethyl alcohol and potassium cyanate.

$$C_2H_5O{-}C{\equiv}N + KOH = C_2H_5OH + KCNO.$$

Both the method of formation and of decomposition indicate that the hydrocarbon radical of the cyanates is combined with oxygen.

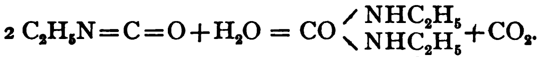
Ethyl Isocyanate, or Ethyl Carbonimide, $C_2H_5N{=}C{=}O$, is formed when a mixture of ethyl potassium sulphate and potassium cyanate is distilled.

$$KC_2H_5SO_4 + KCNO = C_2H_5{-}N{=}C{=}O + K_2SO_4.$$

The isocyanates give amines and carbon dioxide when treated with alkalies.

$$C_2H_5N{=}C{=}O + 2\ KOH = \underset{\text{Ethyl amine.}}{C_2H_5NH_2} + K_2CO_3.$$

With water they give carbon dioxide and alkyl ureas.



$$2\ C_2H_5N{=}C{=}O + H_2O = CO\begin{matrix}\diagup NHC_2H_5\\ \diagdown NHC_2H_5\end{matrix} + CO_2.$$

Diethyl carbamide
or diethyl urea.

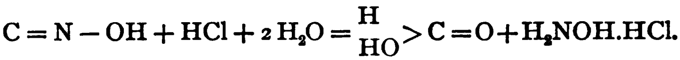
These reactions demonstrate that the radical is united with the nitrogen atom in the isocyanates, or, as they are better called, the carbonimides.

Phenyl Isocyanate, or Phenyl Carbonimide, $C_6H_5N{=}C{=}O$, may be prepared by passing carbonyl chloride (phosgene) over aniline chloride under pressure.

$$C_2H_5NH_2HCl + COCl_2 = C_6H_5N{=}C{=}O + 3\ HCl.$$

It is a liquid with a penetrating odor and having a specific gravity of 1.092 at 15°. It boils at 166°.

Fulminic Acid, $C=N-O-H$ (?) When ethyl alcohol is treated with nitric acid and mercuric nitrate, mercuric fulminate, $HgC_2N_2O_2$, is formed. This is used in percussion caps for firearms, and in fulminating caps for firing dynamite and gun-cotton. When mercuric fulminate is decomposed by hydrochloric acid it gives formic acid and hydroxylamine chloride. This decomposition indicates that it has the structure given above.



$$C=N-OH+HCl+2H_2O=\begin{matrix}H\\HO\end{matrix}\!\!>C=O+H_2NOH.HCl.$$

Formic acid. Hydroxylamine chloride.

In 1823 Liebig demonstrated that silver fulminate, AgCNO, has the same composition as silver cyanate. This was the first case of isomerism discovered, and may be considered as the first step toward the study of structure in chemistry.

THIOCYANATES.

Corresponding to the cyanates, isocyanates, and closely related alkyl ureas, is a whole series of compounds in which the oxygen is replaced by sulphur.

Potassium Thiocyanate, or, as it is more often called, potassium sulphocyanide, KCNS, is formed by heating a mixture of potassium cyanide and sulphur, or even by boiling a solution of potassium cyanide with sulphur.

Ammonium Thiocyanate is formed by agitating a mixture of strong ammonia and carbon bisulphide.

$$CS_2+4NH_3=NH_4-SNC+(NH_4)_2S.$$

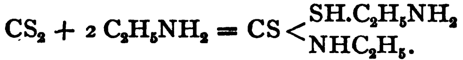
The thiocyanates are used commercially in dyeing.

Ethyl Thiocyanate, $C_2H_5-S-C\equiv N$, is prepared by distilling a mixture of potassium ethyl sulphate and potassium thiocyanate. Its structure is established by the formation of ethyl mercaptan, or a sulphur alcohol, by its reduction, and of ethyl sulphonic acid by its oxidation.

$$C_2H_5S - CN + 6\,H = \underset{\text{Ethyl mercaptan.}}{C_2H_5SH} + \underset{\text{Methyl amine.}}{CH_3NH_2}$$

$$C_2H_5S - CN \rightarrow \underset{\text{Ethyl sulphonic acid.}}{C_2H_5 - SO_3H.}$$

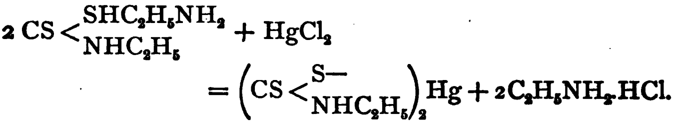
Isothiocyanates or Mustard Oils. — Carbon bisulphide combines with primary amines to form ammonium salts of dithiocarbamic acid, $CS{<}\begin{matrix}SH\\NH_2\end{matrix}$.



$$CS_2 + 2\,C_2H_5NH_2 = CS{<}\begin{matrix}SH.C_2H_5NH_2\\NHC_2H_5.\end{matrix}$$

Ethylamine. Ethyl ammonium ethyl dithiocarbamate.

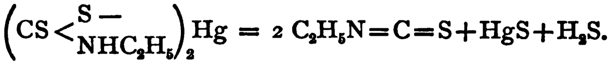
This ammonium salt gives, with mercuric chloride, a mercuric salt of *ethyl dithiocarbamic acid.*



$$2\,CS{<}\begin{matrix}SHC_2H_5NH_2\\NHC_2H_5\end{matrix} + HgCl_2 = \left(CS{<}\begin{matrix}S-\\NHC_2H_5\end{matrix}\right)_2 Hg + 2C_2H_5NH_2.HCl.$$

Mercuric ethyl dithiocarbamate.

When this mercuric salt is heated it decomposes with the formation of an isothiocyanate.



$$\left(CS{<}\begin{matrix}S-\\NHC_2H_5\end{matrix}\right)_2 Hg = 2\,C_2H_5N{=}C{=}S + HgS + H_2S.$$

The structure of the isothiocyanates follows both from their formation as just given, and from their decomposition by acids, which gives an amine and carbonyl sulphide.

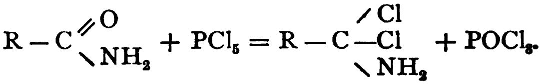
$$2\,C_2H_5N = C = S + H_2SO_4 + 2\,H_2O = \underset{\text{Ethyl ammonium sulphate.}}{(C_2H_5NH_2)_2H_2SO_4} + 2\,COS.$$

The isothiocyanates are substances with an extremely penetrating, disagreeable odor. As they are produced only from primary amines by the above reactions, their formation is sometimes used to distinguish primary from secondary and tertiary amines.

Allyl Isothiocyanate, $CH_2 = CH - CH_2 - N = C = S$, is found in the form of a glucoside of its potassium salt in mustard, and can be obtained from that source by fermentation (see amygdalin, p. 182). This occurrence of allyl isothiocyanate has led to the designation of all of the isothiocyanates as "mustard oils."

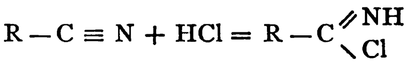
AMIDE CHLORIDES, IMIDE CHLORIDES, IMIDO ESTERS, AMIDINES.

By the action of phosphorus pentachloride on amides we should expect the formation of an amide chloride:



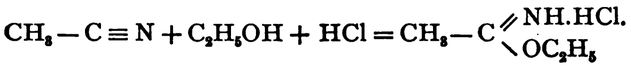
$$R-C\begin{smallmatrix}\nearrow O\\ \searrow NH_2\end{smallmatrix} + PCl_5 = R-C\begin{smallmatrix}\nearrow Cl\\ -Cl\\ \searrow NH_2\end{smallmatrix} + POCl_3.$$

Compounds of this type can, apparently, exist only when the two hydrogen atoms of the amide group have been replaced by hydrocarbon radicals. Otherwise they pass at once into *imide chlorides*, $R-C\begin{smallmatrix}\nearrow NH\\ \searrow Cl\end{smallmatrix}$, which may be considered as acid chlorides in which oxygen has been replaced by the imide (NH) group. The imide chlorides are also formed by the action of hydrochloric acid on nitriles.



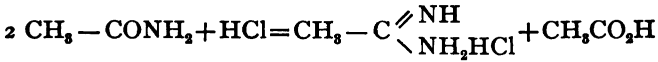
$$R-C \equiv N + HCl = R-C\begin{smallmatrix}\nearrow NH\\ \searrow Cl\end{smallmatrix}$$

Imido esters are obtained in the form of their chlorides by the action of dry hydrochloric acid upon a mixture of equimolecular proportions of a nitrile and an alcohol diluted with ether.



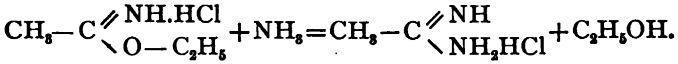
$$CH_3-C\equiv N+C_2H_5OH+HCl=CH_3-C\begin{matrix}{=}NH.HCl.\\ {-}OC_2H_5\end{matrix}$$

Amidines are formed by heating an amide in a current of hydrochloric acid, or by treating a chloride of an imido ester with ammonia.



$$2\,CH_3-CONH_2+HCl=CH_3-C\begin{matrix}{=}NH\\ {-}NH_2HCl\end{matrix}+CH_3CO_2H$$

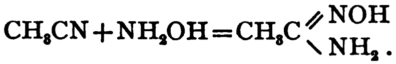
Chloride of acetamidine.



$$CH_3-C\begin{matrix}{=}NH.HCl\\ {-}O-C_2H_5\end{matrix}+NH_3=CH_3-C\begin{matrix}{=}NH\\ {-}NH_2HCl\end{matrix}+C_2H_5OH.$$

The amidines are strong monacid bases.

Amidoximes of the aliphatic series are formed by the union of nitriles and hydroxylamine.



$$CH_3CN+NH_2OH=CH_3C\begin{matrix}{=}NOH\\ {-}NH_2.\end{matrix}$$

The amidoximes are both weak acids and weak bases, forming salts both with metals and with acids.

Laboratory Exercises.

Preparation of the following substances:

1. Acetyl chloride.
2. Acetic anhydride.
3. Succinic anhydride.
4. Acetic ester.
5. Phenyl benzoate.
6. Diethyl ester of tartaric acid.
7. Urea.
8. Uric acid.
9. Alloxan.
10. Acetamide.

11. Benzamide.
12. Phthalamidic acid.
13. Ethyl cyanide.
14. Phenyl cyanide from benzamide.
15. Phenyl cyanide from aniline.
16. Phenyl isocyanide (as a test tube reaction).
17. Ammonium thiocyanate.

CHAPTER XV.

HYDROXY ACIDS.

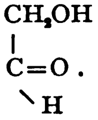
HYDROXY acids are, at the same time, acids and alcohols. As very many of the hydroxy acids and their derivatives form important natural compounds, a considerable number of them were discovered and studied long before their structural nature was understood. As they differ from the simple acids from which they are derived only in containing an additional oxygen atom, they were very early called "oxy" acids. This term still clings to them, and to similar compounds, and is very often used in place of the more accurate designation, "hydroxy," partly for the historical reason given, partly because the longer prefix often seems more cumbersome. The prefix "oxy," with very few exceptions, really means "hydroxy."

ACIDS, $C_nH_{2n}O_3$.

Carbonic Acid, $\mathrm{CO}<\begin{matrix}\mathrm{OH}\\ \mathrm{OH}\end{matrix}$, may be considered as hydroxyformic acid, and so, as the first hydroxy acid. But just as the presence of only a single carbon atom causes formic acid to conduct itself partly as an aldehyde (p. 225), so carbonic acid is rather a bibasic acid than an alcohol (or hydroxy) acid. The more important derivatives of carbonic acid have already been considered (pp. 284 and 290).

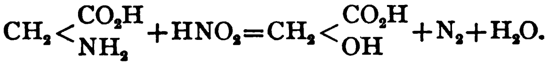
Glycolic Acid (ethanolic acid), $\mathrm{CH_2}<\begin{matrix}\mathrm{CO_2H}\\ \mathrm{OH}\end{matrix}$, is prepared:

1. By the oxidation of glycol, $\begin{matrix}CH_2OH\\ |\\ CH_2OH\end{matrix}$, or glycol aldehyde (ethanolal),



2. By boiling monochloracetic acid, $CH_2<\begin{smallmatrix}CO_2H\\ Cl\end{smallmatrix}$, with water, or with marble dust and water.

3. By treating glycocoll with nitrous acid,



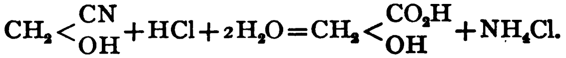
$$CH_2<\begin{matrix}CO_2H\\ NH_2\end{matrix}+HNO_2=CH_2<\begin{matrix}CO_2H\\ OH\end{matrix}+N_2+H_2O.$$

Glycocoll or Aminoacetic acid. **Glycolic acid.**

4. From formaldehyde through the cyanhydrin (p. 178).

$$H-C\begin{matrix}\diagup H\\ \diagdown\!\!\diagdown O\end{matrix}+HCN=CH_2<\begin{matrix}CN\\ OH\end{matrix}$$

Cyanhydrin of formaldehyde.



$$CH_2<\begin{matrix}CN\\ OH\end{matrix}+HCl+2H_2O=CH_2<\begin{matrix}CO_2H\\ OH\end{matrix}+NH_4Cl.$$

It will be noticed that the first method is simply one of the most common methods of preparing acids, while the second and third methods are common methods of preparing alcohols. The fourth method is a general method of preparing α-hydroxy acids from aldehydes or ketones.

Glycolic acid has been found in nature in green grapes, in the leaves of the wild grape-vine, and in beets. It crystallizes in needles or leaflets which melt at 80°. It cannot be distilled without decomposition, and is only slightly volatile with water vapor.

Glycolic acid is a moderately strong acid.

For acetic acid, CH_3CO_2H, $K=0.0018$.
For glycolic acid, $CH(OH)CO_2H$, $K=0.0152$.

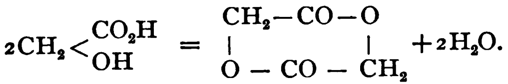
Esters and Ethers of Glycolic Acid. — Glycolic acid forms esters and ethers of the five types which can be predicted from its double nature as alcohol and acid. The following compounds are illustrations:

		Boiling Point.
1. Ethyl glycolate	$CH_2<\begin{matrix}CO_2C_2H_5\\OH\end{matrix}$	160°
2. Ethyl ether of glycolic acid (Ethoxy acetic acid)	$CH_2<\begin{matrix}CO_2H\\OC_2H_5\end{matrix}$	207°
3. Glycolic acetate	$CH_2<\begin{matrix}CO_2H\\OC_2H_3O\end{matrix}$	—
4. Ethyl ether of glycolic ester (Ethoxy acetic ester)	$CH_2<\begin{matrix}CO_2C_2H_5\\OC_2H_5\end{matrix}$	152°
5. Ethyl ester of glycolic acetate	$CH_2<\begin{matrix}CO_2C_2H_5\\OC_2H_3O\end{matrix}$	179°

The chemical conduct of these bodies can be predicted from their structure. Thus 1, 3, and 5 can be completely saponified by boiling with alkalies, 4 can be half saponified, while 2 remains unaffected. The ether groups may, however, be decomposed by hydriodic acid (p. 167), giving ethyl iodide and glycolic acid.

$$CH_2<\begin{matrix}CO_2H\\OC_2H_5\end{matrix}+HI=CH_2<\begin{matrix}CO_2H\\OH\end{matrix}+C_2H_5I.$$

Glycolid. — When glycolic acid is heated in a current of carbon dioxide at 210°, and subsequently distilled in a vacuum, it loses water and forms an anhydride glycolid.



$$2CH_2<\begin{matrix}CO_2H\\OH\end{matrix}=\begin{array}{l}CH_2-CO-O\\ | \qquad\qquad\quad |\\ O-CO-CH_2\end{array}+2H_2O.$$

Glycolid.

Glycolid melts at 86°–87°. It crystallizes from alcohol in shining leaflets.

Lactic Acids (**α-hydroxypropionic acids, 2-propanolic acids**), $CH_3-CH<\begin{matrix}OH\\CO_2H.\end{matrix}$ Since α-hydroxypropionic acid contains an asymmetric carbon atom, it may exist in the right and left active forms, and in the racemic or inactive mixture of the two forms.

d-Lactic Acid, or Dextrolactic Acid, is found in extract of beef, is formed by the fermentation of milk sugar, cane sugar, or glucose under special conditions, especially by the fermentation of glucose under the influence of *micrococcus acidi paralactici;* by the action of *penicillium glaucum* (which destroys the left-handed form of the acid) upon i-ammonium lactate; and by crystallization of the strychnine salt of i-lactic acid, the salt of the leavo-acid crystallizing first. These methods of preparation are not so much of interest in themselves as in illustrating common methods of preparing active compounds.

l-Lactic Acid, or Laevolactic Acid, is formed by the fermentation of milk sugar, cane sugar, glucose, or glycerol under the influence of the *bacillus acidi laevolactici* at a temperature of 36°. It has also been prepared from the inactive acid by means of the strychnine salt (see above).

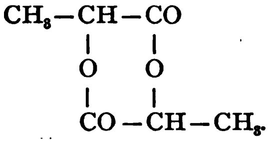
i-Lactic Acid, or Racemic Lactic Acid, has been prepared synthetically by processes similar to each of the four methods given for glycolic acid (p. 314). The details need not be repeated. As is always the case with a synthetic compound prepared from inactive materials, the synthetic acid is inactive. The acid has also been prepared by the reduction of *pyroracemic acid*, CH_8COCO_2H, and by a great variety of both fermentation and chemical methods from various sugars. It is present in sour milk, and is often found in liquids which have undergone alcoholic fermentation.

Pure i-lactic acid is a syrup which has a specific gravity of

1.2485 at $\frac{15^\circ}{4^\circ}$. It cannot be distilled without decomposition.

It is a moderately strong acid, $K = 0.0138$.

When heated to 150° in a current of dry air, lactic acid is converted into an anhydride called *lactid.*



Lactid is an indifferent body. In contact with water it is slowly converted back to lactic acid.

It melts at 124°, and boils at 255°.

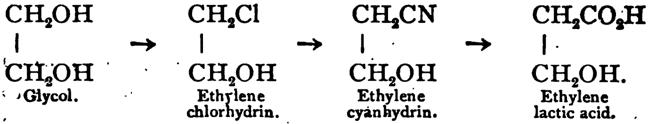
When lactic acid is distilled it decomposes into water, lactid, aldehyde, carbon dioxide, and carbon monoxide. With lead peroxide and sulphuric acid it gives aldehyde and carbon dioxide. This is one of the general methods of preparing aldehydes and ketones (p. 218), and is the reverse of the preparation of α-hydroxy acids through the cyanhydrin from aldehydes. Both reactions establish the structure of lactic acid.

By heating with hydriodic acid, lactic acid is reduced to propionic acid.

$$CH_3CH(OH)CO_2H + HI = \underset{\alpha\text{-Iodopropionic acid.}}{CH_3CHICO_2H} + H_2O$$

$$CH_3CHICO_2H + HI = CH_3CH_2CO_2H + I_2.$$

β-Hydroxypropionic Acid (ethylene lactic acid, hydracrylic acid, 3-propanolic acid), $CH_2(OH)CH_2CO_2H$, may be prepared through the following series of compounds:



$$\underset{\text{Glycol.}}{\begin{array}{c}CH_2OH\\ |\\ CH_2OH\end{array}} \rightarrow \underset{\text{Ethylene chlorhydrin.}}{\begin{array}{c}CH_2Cl\\ |\\ CH_2OH\end{array}} \rightarrow \underset{\text{Ethylene cyanhydrin.}}{\begin{array}{c}CH_2CN\\ |\\ CH_2OH\end{array}} \rightarrow \underset{\text{Ethylene lactic acid.}}{\begin{array}{c}CH_2CO_2H\\ |\\ CH_2OH.\end{array}}$$

β-Hydroxypropionic acid is a much weaker acid than the α-hydroxy acid, K = 0.00311. When heated, the acid decomposes with the formation of acrylic acid:

$$CH_2(OH)CH_2CO_2H = \underset{\text{Acrylic acid.}}{CH_2=CH-CO_2H} + H_2O.$$

This decomposition is characteristic of β-hydroxy acids in general, and distinguishes them from the α- and γ-hydroxy acids. Some of the β-hydroxy acids lose water even on heating with a solution of sodium hydroxide.

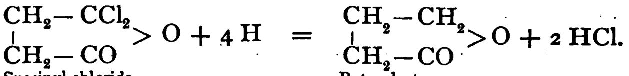
β-Hydroxybutyric Acid (3-butanolic acid),

$$CH_3CHOHCH_2CO_2H,$$

is formed by the reduction of a cold dilute solution of acetacetic acid, $CH_3COCH_2CO_2H$. It is a syrup which decomposes, on heating, into water and *crotonic acid*,

$$CH_3CH=CH-CO_2H \text{ (see above).}$$

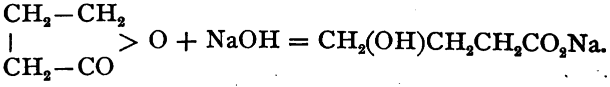
γ-Hydroxybutyric Acid (4-butanolic acid).— The anhydride of this acid is formed by reducing an ethereal solution of succinyl chloride with sodium amalgam:



$$\underset{\text{Succinyl chloride.}}{\begin{array}{l}CH_2-CCl_2\\ |\\ CH_2-CO\end{array}} > O + 4\,H = \underset{\text{Butyrolactone.}}{\begin{array}{l}CH_2-CH_2\\ |\\ CH_2-CO\end{array}} > O + 2\,HCl.$$

Succinyl chloride. Butyrolactone.

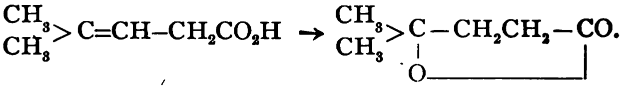
Salts of the acid may be obtained by warming the anhydride, *butyrolactone*, with alkalies:



$$\begin{array}{l}CH_2-CH_2\\ |\\ CH_2-CO\end{array} > O + NaOH = CH_2(OH)CH_2CH_2CO_2Na.$$

The free acid is a liquid. It loses water very easily when warmed, and passes back into the *lactone*. The lactone is to be considered as a sort of "inner" ester, somewhat analogous to the "inner" anhydrides of bibasic acids. The formation of such anhydrides, called *lactones*, is especially characteristic of γ-hydroxy acids. A few similar lactones are known for acids in which the hydroxyl occupies the δ- or ε-position with regard to the carboxyl, but only the γ-lactones are common and easily formed.

Not only do the γ-hydroxy acids readily yield lactones, but the β-γ-unsaturated acids, when warmed with dilute sulphuric acid (1 : 1), pass over into the isomeric lactones.

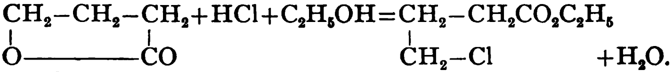


$$\begin{matrix}CH_3\\CH_3\end{matrix}\!>C{=}CH{-}CH_2CO_2H \rightarrow \begin{matrix}CH_3\\CH_3\end{matrix}\!>\begin{array}{l}C-CH_2CH_2-CO.\\ |\qquad\qquad\qquad\quad\ \ |\\ O\text{—————————}\end{array}$$

Δ^2 Methyl-4-pentenoic acid (Pyroterebic acid).

Methyl-4-pentanolid 1.4 (Isocaprolactone).

Butyrolactone (butanolid 1.4), $\begin{array}{l}CH_2-CH_2CH_2\\ |\qquad\qquad\quad |\\ O\text{————}CO\end{array}$, is an oil which boils at 206°, and has a specific gravity of 1.1286 at $\frac{15^\circ}{0^\circ}$. It mixes with water in all proportions, but separates, from not too dilute a solution, on the addition of potassium carbonate. It is easily volatile with water vapor. When treated with alcohol and hydrochloric acid, it gives the ethyl ester of γ-chlorbutyric acid.

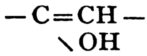
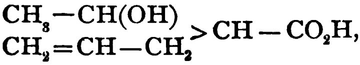


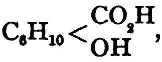
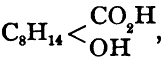
$$\begin{array}{l}CH_2-CH_2-CH_2\\ |\qquad\qquad\quad\ |\\ O\text{—————}CO\end{array}+HCl+C_2H_5OH=\begin{array}{l}CH_2-CH_2CO_2C_2H_5\\ |\\ CH_2-Cl\end{array}+H_2O.$$

Butyrolactone. Ethyl γ-chlorbutyrate.

γ-Hydroxyisocaproic Acid (4-methyl-4-hydroxy-pentanoic acid), $\begin{matrix}CH_3\\CH_3\end{matrix}\!>C(OH)CH_2CH_2CO_2H$, is prepared by oxidizing *isocaproic acid*, $\begin{matrix}CH_3\\CH_3\end{matrix}\!>CHCH_2CH_2CO_2H$, with an alkaline solution of potassium permanganate at a temperature of 50°–60°. In this, and several other similar cases, it is possible to oxidize a tertiary hydrogen atom directly to a hydroxyl group. The free hydroxy acid is not known, but when liberated it passes easily into *isocaprolactone*, (*methyl-4-pentanolid* 1.4), an oil which solidifies at a low temperature, and melts at 10°. It boils at 208.5°, and resembles butyrolactone in its general properties.

ACIDS, $C_nH_{2n-2}O_3$.

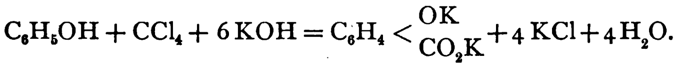
Comparatively few unsaturated hydroxy acids are known. When the grouping  $-\underset{\diagdown OH}{C}=CH-$ ("enol" form) occurs, it generally passes readily into the "tautomeric" (pp. 297, 349) $-CO-CH_2-$ (ketone form), and some of the more important acids of this class will be considered under the aldehyde and ketonic acids. When the double union and hydroxyl groups are separated, as in α-allylhydroxybutyric acid,  $\begin{matrix}CH_3-CH(OH)\\CH_2=CH-CH_2\end{matrix}>CH-CO_2H$, compounds which are true unsaturated hydroxy acids may exist, but such acids exhibit no peculiarities which demand special mention.

Cyclic hydroxy acids of this general formula correspond, in general properties, to the saturated hydroxy acids. To this class belong hexahydrosalicylic acid,  $C_6H_{10}<\begin{matrix}CO_2H\\OH\end{matrix}$, and half a dozen acids,  $C_8H_{14}<\begin{matrix}CO_2H\\OH\end{matrix}$, derived from camphor. γ-Hydroxy acids derived from cyclopentane and cyclohexane form very stable lactones, but there is some evidence which indicates that such lactones are formed only from the trans form. The question is one which requires further experimental evidence.

ACIDS, $C_nH_{2n-8}O_3$.

Very many hydroxy acids of the aromatic series are known, and many of them are important either in themselves or in their derivatives.

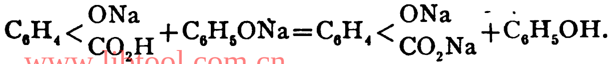
Salicylic Acid, $C_6H_4<\begin{matrix}CO_2H & 1\\ OH & 2\end{matrix}$. The Reimer-Tiemann synthesis of salicylic aldehyde from phenol and chloroform has been given (p. 185). From the aldehyde the acid can be obtained by oxidation. If carbon tetrachloride is used instead of chloroform, salicylic acid will be formed, in part, though the chief product is parahydroxybenzoic acid:



$$C_6H_5OH + CCl_4 + 6\,KOH = C_6H_4 < \begin{matrix}OK\\ CO_2K\end{matrix} + 4\,KCl + 4\,H_2O.$$

Salicylic acid is also prepared:

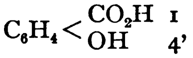
2. By heating sodium phenolate with carbon dioxide. It was formerly supposed that the first product of the reaction is phenyl sodium carbonate, $CO<\begin{matrix}OC_6H_5\\ ONa\end{matrix}$. Tijmstra has shown, however, (*Ber. d. chem. Ges.* 38, 1375) that the carbon dioxide unites directly with the sodium phenolate to form sodium phenolate o-carboxyllic acid, $C_6H_4<\begin{matrix}ONa\\ CO_2H\end{matrix}$. This reaction begins at 85° and is more rapid at higher temperatures. It is carried out in the laboratory by heating sodium phenolate, C_6H_5ONa, with carbon dioxide in an autoclave at 120°–130°, or by heating the phenolate in a slow current of carbon dioxide at atmospheric pressure at 180°–200°. At this temperature, however, the sodium phenolate o-carboxyllic acid dissociates to sodium phenolate and carbon dioxide. The sodium phenolate is, at the same time decomposed by another molecule of the acid giving the disodium salt of salicylic acid and liberating phenol, which distils away.



$$C_6H_4<\genfrac{}{}{0pt}{}{ONa}{CO_2H}+C_6H_5ONa=C_6H_4<\genfrac{}{}{0pt}{}{ONa}{CO_2Na}+C_6H_5OH.$$

Under these conditions only one-half of the phenol is converted into salicylic acid.

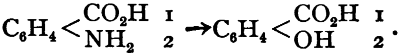
This is known as Kolbe's synthesis, and is quite general in its application, the carboxyl group entering in the ortho position to the hydroxyl. If potassium phenolate is used in place of the sodium salt, salicylic acid is formed at 150°, but, curiously enough, at 220° parahydroxybenzoic acid,



$$C_6H_4<\genfrac{}{}{0pt}{}{CO_2H \quad 1}{OH \quad\;\; 4}$$

is almost exclusively formed.

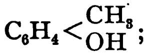
3. By treating a salt of anthranilic acid (o-amino benzoic acid) with nitrous acid, and boiling the aqueous solution of the diazo compound formed (p. 460):



$$C_6H_4<\genfrac{}{}{0pt}{}{CO_2H \quad 1}{NH_2 \quad\; 2}\rightarrow C_6H_4<\genfrac{}{}{0pt}{}{CO_2H \quad 1}{OH \quad\;\; 2}.$$

Anthranilic acid.

4. By fusing with caustic potash; ortho-cresol,

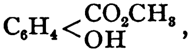


$$C_6H_4<\genfrac{}{}{0pt}{}{CH_3}{OH};$$

ortho toluene sulphonic acid, $C_6H_4<\genfrac{}{}{0pt}{}{CH_3}{SO_3H}$; indigo; or ortho-sulphobenzoic acid, $C_6H_4<\genfrac{}{}{0pt}{}{CO_2H}{SO_3H}$. It is formed in small amount by fusing orthochlorbenzoic acid, $C_6H_4<\genfrac{}{}{0pt}{}{CO_2H}{Cl}$, or metabrombenzoic acid, $C_6H_4<\genfrac{}{}{0pt}{}{CO_2H}{Br}$, with caustic potash, the reaction being accompanied by a rearrangement, and giving, chiefly, metahydroxybenzoic acid in each case. In the first two cases above, the fusion with caustic potash is accompanied by an oxidation.

The necessity of fusing the halogen derivatives of benzoic acid with caustic potash in the preparation of salicylic or metahydroxybenzoic acid illustrates a characteristic difference between aromatic and aliphatic compounds. While chloracetic acid and similar compounds may usually be converted into hydroxy acids by merely boiling with solutions of alkalies, or even with water, aromatic compounds, with very few exceptions (p. 392), are not affected by such treatment.

5. By saponifying *methyl salicylate*,

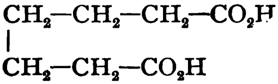


$$C_6H_4<\begin{matrix}CO_2CH_3\\OH\end{matrix},$$

with caustic potash. Methyl salicylate is the chief constituent of the oil of wintergreen.

Salicylic acid crystallizes in needles, which melt at 156°. It has powerful antiseptic properties, resembling phenol in that regard, but without the disagreeable odor and highly poisonous character of the latter. It is often used as an antiseptic in wine, cider, and foods. Its use is objectionable as, while it is not an active poison, it interferes with digestion. It can usually be detected by extracting the acid solution with a mixture of ether and ligroin, separating, evaporating, and testing the residue with a dilute solution of ferric chloride, which gives, with salicylic acid (and with all *ortho*-hydroxy aromatic acids), an intense violet color. *Sodium salicylate* is used as a remedy for rheumatism.

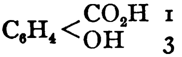
When reduced with amyl alcohol and sodium, salicylic acid gives pimelic acid,



$$\begin{array}{l}CH_2-CH_2-CH_2-CO_2H\\|\\CH_2-CH_2-CO_2H\end{array}$$

(p. 257).

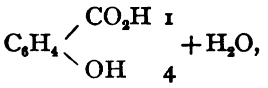
Metahydroxybenzoic Acid (m-oxybenzoic acid),



$$C_6H_4<\begin{matrix}CO_2H & 1\\OH & 3\end{matrix},$$

is prepared by fusing m-sulphobenzoic acid, m-brombenzoic acid, or m-chlorbenzoic acid with caustic potash, or by treating metaminobenzoic acid with nitrous acid. It crystallizes in needles, which melt at 200°.

Parahydroxybenzoic Acid (p-oxybenzoic acid),



$$C_6H_4\begin{matrix}\diagup CO_2H \; 1 \\ \diagdown OH \quad 4\end{matrix} + H_2O,$$

can be prepared by the same general methods as the meta acid. It can also be obtained by the Kolbe synthesis at 220°, if potassium phenolate is used (see salicylic acid). When *anethol* (*p-allylmethoxybenzene*),

$$CH_3CH=CH-C_6H_4OCH_3,$$

the chief constituent of *anise-oil*, is oxidized with nitric acid or chromic acid, anisic acid (p-methoxybenzoic acid), $C_6H_4<^{CO_2H}_{OCH_3}$, is formed. This gives, with hydriodic acid, parahydroxybenzoic acid and methyl iodide.

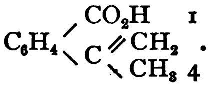
The last method of preparation may be taken as an illustration of methods which can often be used for the preparation of similar compounds. The phenols are so unstable toward oxidizing agents that side chains which they may contain $\left(\text{as in cresols, } C_6H_4<^{CH_3}_{OH}\right)$ cannot be oxidized to carboxyl directly, as is done with other derivatives of benzene. By converting the hydroxyl group into an ether or an ester group (phosphoric or sulphuric esters, as $C_6H_4<^{CH_3}_{O-SO_3H}$, may be used), a compound sufficiently stable for oxidation is, however, formed; and, after oxidation, the ether or ester group may be decomposed, giving the hydroxy acid which is desired.

Paraoxybenzoic acid crystallizes with one molecule of water which it loses at 100°. The anhydrous acid melts at 210°.

Salicylic acid is volatile with steam; m- and p-oxybenzoic acids are not.

Phthalid, $C_6H_4<\begin{matrix}\overset{1.}{CH_2}\\ \underset{2.}{CO}\end{matrix}>O$, is a γ-lactone of the aromatic series. It bears the same relation to phthalic acid which butyrolactone does to succinic acid, and may be prepared in a similar manner.

p-Hydroxyisopropyl Benzoic Acid (4-methoethylol phenmethylic acid), $C_6H_4<\begin{matrix}CO_2H\\ C(OH)<\begin{matrix}CH_3\\ CH_3\end{matrix}\end{matrix}\begin{matrix}1\\ 4\end{matrix}$, is prepared by oxidizing an alkaline solution of *cuminic acid* (p-isopropyl benzoic acid), $C_6H_4\begin{matrix}/CO_2H\\ \backslash CH<\begin{matrix}CH_3\\ CH_3\end{matrix}\end{matrix}\begin{matrix}1\\ 4\end{matrix}$, with potassium permanganate. This is another illustration of the oxidation of a tertiary hydrogen atom. The acid crystallizes in long, thin, triclinic prisms. It melts at 156°. By boiling with dilute hydrochloric acid, or by treatment with acetyl chloride, it loses water and gives *propenyl benzoic acid*,



$$C_6H_4\begin{matrix}/CO_2H\\ \backslash C\begin{matrix}/\!/CH_2\\ \backslash CH_3\end{matrix}\end{matrix}\begin{matrix}1\\ \\ 4\end{matrix}.$$

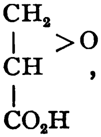
ACIDS, $C_nH_{2n}O_4$.

The dihydroxy acids of the above formula are prepared by treating dihalogen substitution products of the fatty acids with moist silver oxide, or by oxidizing acrylic acid, $CH_2=CH-CO_2H$, or its homologues, with a cold, one per cent solution of potassium permanganate.

Glyoxylic Acid (ethanediolic acid), $CH(OH)_2CO_2H$, is prepared by heating *dibromacetic acid*, $CHBr_2CO_2H$, with water, or by the oxidation of alcohol, glycol, or glycerol, with nitric acid. Glyoxylic acid is to be considered rather as the hydrate of an aldehyde acid than as an ordinary hydroxy acid. It conducts itself as an aldehyde acid, forming an oxime (p. 179) and combining directly with ammonia, hydrogen sulphide, and acid sodium sulphite.

Glyceric Acid (propanediolic acid), $CH_2OHCHOHCO_2H$, is prepared by the careful oxidation of glycerol with nitric acid, or by warming α-β-dibrompropionic acid, $CH_2BrCHBrCO_2H$, with silver oxide and water. By warming with hydriodic acid, glyceric acid is reduced to *β-iodopropionic acid.* (See p. 409.)

Glycidic Acid (epihydrinic acid),

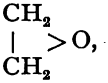


$$\begin{array}{l}CH_2\\ |\quad >O\\ CH\\ |\\ CO_2H\end{array},$$

is formed by treating *β-chlorlactic acid,*

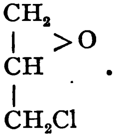
$$CH_2ClCH(OH)CO_2H,$$

with caustic potash. It is a sort of inner ether, similar to ethylene oxide,



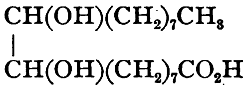
$$\begin{array}{l}CH_2\\ |\quad >O,\\ CH_2\end{array}$$

and epichlorhydrin,



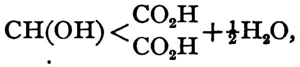
$$\begin{array}{l}CH_2\\ |\quad >O\\ CH\\ |\\ CH_2Cl\end{array}.$$

A considerable number of other compounds of the same type are known. Glycidic acid is volatile, and has a piercing odor. On boiling with water it gives glyceric acid. With hydrochloric acid it gives β-chlorlactic acid. It is evident, therefore, that although an ether in structure it is much less stable than open-chain ethers. Since ethylene oxide exhibits like characteristics, and since similar ethereal rings containing three or four carbon atoms with the oxygen atom are much more stable, it seems probable that the instability is due to tension within the ring (p. 194).

Dioxystearic Acid,  $\begin{array}{l} CH(OH)(CH_2)_7CH_3 \\ | \\ CH(OH)(CH_2)_7CO_2H \end{array}$, is prepared by oxidizing oleïc acid with a cold dilute solution of potassium permanganate. It crystallizes in leaflets, which melt at 136.5°. Further oxidation gives caprylic acid, $C_7H_{15}CO_2H$, suberic acid, $(CH_2)_6(CO_2H)_2$, and azelaic acid, $(CH_2)_7(CO_2H)_2$.

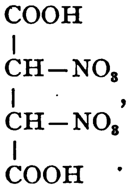
To avoid separating too far substances which are closely related, a somewhat less logical order will be followed in discussing the remaining hydroxy acids, which are to be mentioned.

Tartronic Acid (hydroxymalonic acid),



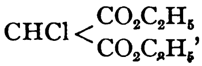
$$CH(OH) < \begin{array}{l} CO_2H \\ CO_2H \end{array} + \tfrac{1}{2}H_2O,$$

is prepared by decomposing *tartaric acid nitrate* ("nitrotartaric acid"),



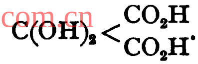
$$\begin{array}{l} COOH \\ | \\ CH-NO_3 \\ | \\ CH-NO_3 \\ | \\ COOH \end{array},$$

with dilute alcohol; by the saponification of *chlormalonic ester*,



$$CHCl < \begin{array}{l} CO_2C_2H_5 \\ CO_2C_2H_5 \end{array},$$

with caustic potash; and by the reduction of mesoxalic acid,



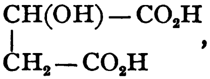
$$C(OH)_2 < \begin{matrix} CO_2H \\ CO_2H \end{matrix}.$$

Tartronic acid sublimes at a low temperature, and melts at 185°–187°, decomposing at the same time into water, carbon dioxide, and glycolid (p. 315).

Mesoxalic Acid, $C(OH)_2 < \begin{matrix} CO_2H \\ CO_2H \end{matrix}$, is formed by boiling *dibrommalonic acid,* $CBr_2 < \begin{matrix} CO_2H \\ CO_2H \end{matrix}$, with barium hydroxide, or by boiling alloxan with barium hydroxide (p. 293). Mesoxalic acid crystallizes in needles which melt, with decomposition, at 120°. It illustrates, again, the possibility of two hydroxyl groups being combined with a carbon atom which is, at the same time, combined with strongly negative groups. The concentrated solution is decomposed, by long boiling, into carbon dioxide and *glyoxylic acid,* $CH(OH)_2CO_2H$. This decomposition is closely related to the decomposition of acetoacetic acid, $CH_3COCH_2CO_2H$, (p. 351).

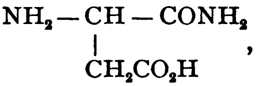
The barium and calcium salts of mesoxalic acid are very difficultly soluble in water.

Malic Acid (hydroxysuccinic acid),



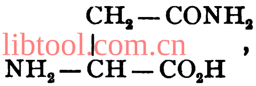
$$\begin{matrix} CH(OH)-CO_2H \\ | \\ CH_2-CO_2H \end{matrix},$$

is found in apples, cherries, unripe grapes, tobacco leaves, and in a great variety of fruits and plants. It is prepared by treating either *α-asparagine,*



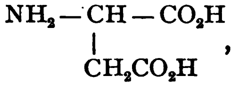
$$\begin{matrix} NH_2-CH-CONH_2 \\ | \\ CH_2CO_2H \end{matrix},$$

β-asparagine,



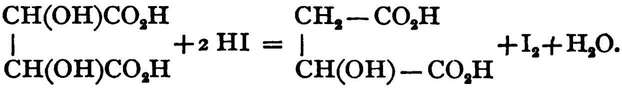
$$\begin{array}{l} \phantom{NH_2 - {}}CH_2 - CONH_2 \\ \phantom{NH_2 - {}}| \\ NH_2 - CH - CO_2H \end{array},$$

or *aspartic acid,*



$$\begin{array}{l} NH_2 - CH - CO_2H \\ \phantom{NH_2 - {}}| \\ \phantom{NH_2 - {}}CH_2CO_2H \end{array},$$

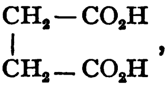
with nitrous acid, or by the partial reduction of tartaric acid with hydriodic acid:



$$\begin{array}{l} CH(OH)CO_2H \\ | \\ CH(OH)CO_2H \end{array} + 2\,HI = \begin{array}{l} CH_2 - CO_2H \\ | \\ CH(OH) - CO_2H \end{array} + I_2 + H_2O.$$

Malic acid exists in two optically active forms, and in an inactive form. Some confusion has arisen in the designation of the two active forms from the fact that the natural acid, obtained from the berries of the European mountain ash, is laevo-rotatory in moderately dilute solutions, but becomes dextro-rotatory in concentrated solutions or in the presence of a strong mineral acid. The malic acid obtained by the reduction of dextro-tartaric acid shows an exactly opposite conduct. It would seem from this that the ion of malic acid which results from its dissociation in aqueous solution gives a rotation which is opposite to that of the molecules which are not ionized. On the other hand, it has been found that the acid which is dextro-rotatory in concentrated solutions is laevo-rotatory in acetone. Whether it is also ionized in acetone has not, apparently, been determined. A further study of the relations involved seems desirable.

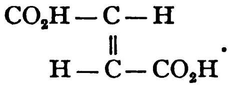
Malic acid is reduced to succinic acid,



$$\begin{array}{l} CH_2 - CO_2H \\ | \\ CH_2 - CO_2H \end{array},$$

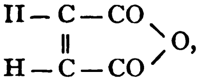
by hydriodic acid.

When malic acid is heated for some time to 120°–130°, it loses water, and gives fumaric acid,



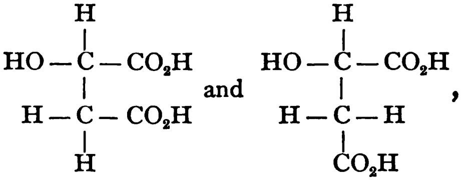
$$\begin{array}{r} \mathrm{CO_2H-C-H} \\ \| \quad\;\; \\ \mathrm{H-C-CO_2H} \end{array}.$$

If heated rapidly to 200°, maleïc anhydride,



$$\begin{array}{l} \mathrm{H-C-CO} \diagdown \\ \quad\;\; \| \qquad\quad\;\; \mathrm{O}, \\ \mathrm{H-C-CO} \diagup \end{array}$$

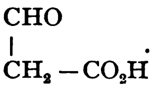
distills over. If we consider the two possible configurations,



$$\begin{array}{c} \mathrm{H} \\ | \\ \mathrm{HO-C-CO_2H} \\ | \\ \mathrm{H-C-CO_2H} \\ | \\ \mathrm{H} \end{array} \quad \text{and} \quad \begin{array}{c} \mathrm{H} \\ | \\ \mathrm{HO-C-CO_2H} \\ | \\ \mathrm{H-C-H} \\ | \\ \mathrm{CO_2H} \end{array},$$

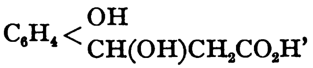
for malic acid, it will be seen that the first, in which the carboxyl groups are on the same side, would give maleïc acid by the loss of water, while the second would give fumaric acid. From this it would seem that malic acid naturally assumes a configuration in which the carboxyl groups are not on the same side of the molecules. In the discussion of this and similar stereochemical problems the first configuration is called "unfavorable," the second "favorable" or "preferred" (German *begünstigt*).

Condensations with Malic Acid. — When a mixture of malic acid and phenol is heated with concentrated sulphuric acid, coumarin is formed. The malic acid seems to decompose at first into water, carbon monoxide, and an aldehyde acid,



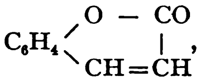
$$\begin{array}{l} \mathrm{CHO} \\ | \\ \mathrm{CH_2-CO_2H} \end{array}.$$

The last compound condenses with the phenol in the ortho-position, to form *phenylol-β-hydroxypropionic acid,*

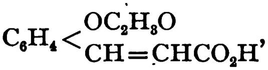


$$C_6H_4<\begin{matrix}OH\\CH(OH)CH_2CO_2H\end{matrix},$$

and this gives coumarin,



by loss of two molecules of water. Coumarin is a δ-lactone. The acetyl derivative of the corresponding *coumaric acid,*

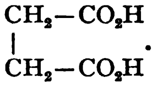


$$C_6H_4<\begin{matrix}OC_2H_3O\\CH{=}CHCO_2H\end{matrix},$$

is formed by heating a mixture of salicylic aldehyde, sodium acetate, and acetic anhydride; and this, on further heating, loses acetic acid and passes over into coumarin. This preparation of coumarin is of especial interest because it was the first illustration discovered of Perkin's synthesis (p. 244).

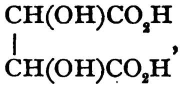
Tartaric Acid (dihydroxysuccinic acid), $C_4H_6O_6$, is found in grapes, and in many plants and fruits, partly free, partly in the form of its potassium or calcium salts. The acid potassium salt, $KC_4H_5O_6$, is difficultly soluble in water, and is much less soluble in dilute alcohol. It is deposited in wine-casks, and is known as *argol* in its crude form, or as *cream of tartar* when purified. The pure salt is mixed with sodium bicarbonate in some kinds of baking powders.

The structure of tartaric acid was established in the following manner. When tartaric acid is treated with hydrochloric acid and alcohol, it is converted into a diethyl ester, $C_4H_4O_6\ (C_2H_5)_2$, which can be purified by distillation under diminished pressure. This establishes the presence of two carboxyl groups, and gives the formula $C_2H_4O_2\ (CO_2H)_2$. If the diethyl ester is treated with acetyl chloride, or with acetic anhydride and sodium hydroxide (p. 282) a *diacetyl tartaric ester*, $C_2H_2\,(OC_2H_3O)_2\,(CO_2C_2H_5)_2$, is formed. This establishes the presence of two alcoholic hydroxyl groups, and gives the formula, $C_2H_2\,(OH)_2\,(CO_2H)_2$. Finally, by reduction with hydriodic acid, tartaric acid has been converted into succinic acid,



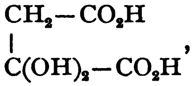
$$\begin{array}{l} CH_2-CO_2H \\ | \\ CH_2-CO_2H \end{array}.$$

This leads to the formula,



$$\begin{array}{l} CH(OH)CO_2H \\ | \\ CH(OH)CO_2H \end{array},$$

for the tartaric acid. The alternative formula,



$$\begin{array}{l} CH_2-CO_2H \\ | \\ C(OH)_2-CO_2H \end{array},$$

is excluded by the facts of the comparative stability of tartaric acid, and of its optical activity (?).

Tartaric acid contains *two* asymmetric carbon atoms. As, further, the molecule may be thought of as consisting of two exactly equal parts, the acid furnishes a very interesting illustration of the possibilities of optical isomerism. The theory indicates the following possibilities, which have been fully verified by the facts:

I. The two halves may each turn the ray of polarized light to the right. This gives the ordinary or *dextrotartaric acid*, which melts at 168°–170°.

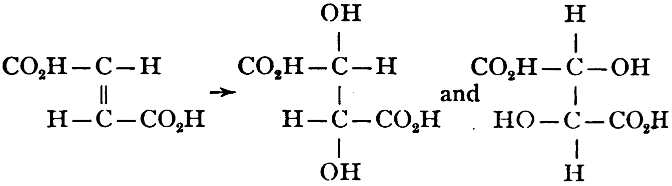
II. The two halves may each turn the ray to the left. This gives *laevotartaric acid*, melting at 168°–170°.

III. A mixture of the first two acids in equal proportions is inactive, and is called *racemic acid.* Racemic acid was the first inactive compound to be resolved into its component active parts. In making a careful study of the acid, which is found as a by product in the preparation of tartaric acid, Pasteur noticed that the sodium ammonium salt deposited two kinds of crystals. These crystals exhibited hemihedral faces, which were so related that one crystal corresponded to the image in the mirror of the other. On examining the acid from these salts he found, to his surprise, that the acid from one set of crystals was dextrorotatory, while that from the other crystals was laevorotatory, (*Ann. Chem.* [3] 28, 56 (1848)). This remarkable discovery must be considered as the first beginning from which the theories of stereochemistry were finally developed. The crystallization, to be successful, must take place at temperatures below 28°. Racemic acid melts at 205°–206°. It crystallizes with one molecule of water, while ordinary tartaric acid crystallizes free of water. Calcium racemate, $Ca(C_4H_4O_6)_2$, is less soluble than calcium tartrate. The acid potassium salt of racemic acid is, however, more soluble than cream of tartar.

Racemic acid can be prepared by mixing equal parts of dextro- and laevotartaric acid. It is also formed, together with mesotartaric acid (see below), when either of the tartaric acids is heated for some time with water at 175°, in a sealed tube.

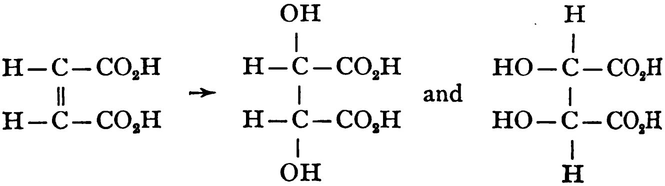
IV. If one-half of the molecule of tartaric acid turns the plane of polarized light to the right, and the other half turns it to the left, each will counterbalance the effect of the other, and an acid will be produced which will be inactive, and which cannot be separated into active forms. This is believed to be the character of *mesotartaric acid.* Mesotartaric acid is formed, in part, when either of the tartaric acids is heated with water to 165° for two days. If mesotartaric acid is itself heated to 200° till one-third of it is decomposed, a portion of it is converted into racemic acid. Mesotartaric acid melts at 139°–143°. Its salts, also, differ from those of either of the other tartaric acids.

The theory which has been given of the relation between the four tartaric acids finds a very interesting confirmation in their formation from fumaric and maleïc acids. When fumaric acid is oxidized with a dilute solution of potassium permanganate, racemic acid is formed, while maleïc acid gives, in the same manner, mesotartaric acid. (Kekulè and Anschütz, *Ber. d. chem. Ges.* 13, 2150; 14, 713.)



$$\begin{array}{c} \mathrm{CO_2H-C-H} \\ \| \\ \mathrm{H-C-CO_2H} \end{array} \rightarrow \begin{array}{c} \mathrm{OH} \\ | \\ \mathrm{CO_2H-C-H} \\ | \\ \mathrm{H-C-CO_2H} \\ | \\ \mathrm{OH} \end{array} \text{ and } \begin{array}{c} \mathrm{H} \\ | \\ \mathrm{CO_2H-C-OH} \\ | \\ \mathrm{HO-C-CO_2H} \\ | \\ \mathrm{H} \end{array}$$

Fumaric acid. Racemic acid.

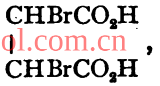


$$\begin{array}{c} \mathrm{H-C-CO_2H} \\ \| \\ \mathrm{H-C-CO_2H} \end{array} \rightarrow \begin{array}{c} \mathrm{OH} \\ | \\ \mathrm{H-C-CO_2H} \\ | \\ \mathrm{H-C-CO_2H} \\ | \\ \mathrm{OH} \end{array} \text{ and } \begin{array}{c} \mathrm{H} \\ | \\ \mathrm{HO-C-CO_2H} \\ | \\ \mathrm{HO-C-CO_2H} \\ | \\ \mathrm{H} \end{array}$$

Maleïc acid. Mesotartaric acid.

It can be seen from the formulae, and more clearly from models, that the forms produced from fumaric acid are optical isomers, while the forms from maleïc acid are inactive by internal compensation and are identical.

Both racemic and mesotartaric acid are formed when *bibromsuccinic acid*,



$$\begin{array}{l} CHBrCO_2H \\ | \\ CHBrCO_2H \end{array},$$

from fumaric acid, is treated with silver oxide and water. Isobibromsuccinic acid, from maleïc acid, on the other hand, gives racemic acid only. These facts do not agree with the theory just given, and, together with a considerable number of similar facts, are considered by some as evidence against the validity of the stereochemical theory which has been presented. While such a conclusion seems scarcely warranted in the face of the large mass of affirmative evidence which has been accumulated, such cases demonstrate the necessity of care in applying the theory, and show that molecular rearrangements which lead to conflicting results are especially liable to occur with this class of bodies.

A large number of tartrates have been prepared. The most interesting are cream of tartar (see above), a similar acid ammonium salt, which is difficultly soluble, *potassium antimonyl tartrate*, or *tartar emetic*,

$$KSbOC_4H_4O_6 + \tfrac{1}{2}H_2O,$$

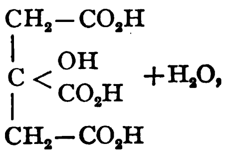
the sodium ammonium salt,

$$NaNH_4C_4H_4O_6 + 4H_2O,$$

and the sodium potassium salt, or Rochelle salt,

$$KNaC_4H_4O_6 + 4H_2O.$$

Citric Acid (hydroxytricarballylic acid),



$$\begin{array}{l} CH_2-CO_2H \\ | \\ C<\begin{array}{l} OH \\ CO_2H \end{array} \quad + H_2O, \\ | \\ CH_2-CO_2H \end{array}$$

is found in lemons, and in very many other natural products. It is obtained, commercially, from green lemons, the acid in the lemon juice being converted into the difficultly soluble calcium citrate, $Ca_3(C_6H_5O_7)_2+4\,H_2O$, and the salt decomposed with sulphuric acid.

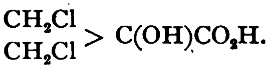
Citric acid has also been prepared synthetically in several different ways. When glycerol is treated with hydrochloric acid at 120°–130°, symmetric dichlorhydrin,

$$CH_2ClCH(OH)CH_2Cl,$$

is formed. This gives, by oxidation, a dichloracetone,

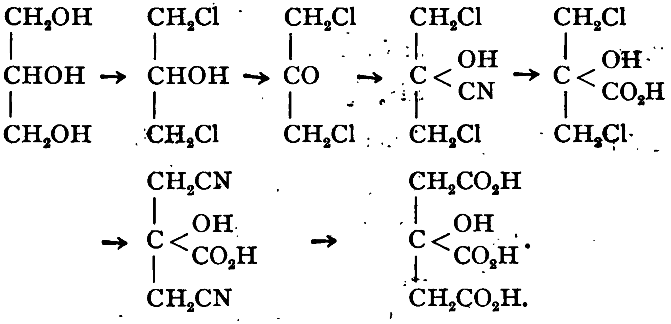
$$CH_2ClCOCH_2Cl,$$

and the latter, with hydrocyanic acid, the cyanhydrin, which can be saponified to dichlorhydroxyisobutyric acid,



$$\begin{array}{l}CH_2Cl\\ CH_2Cl\end{array} > C(OH)CO_2H.$$

This, with potassium cyanide, gives the dicyanide, from which citric acid is obtained by saponification. The transformations will be clearer from the following diagram:

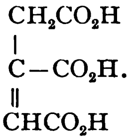


$$\begin{array}{c}CH_2OH\\ |\\ CHOH\\ |\\ CH_2OH\end{array} \rightarrow \begin{array}{c}CH_2Cl\\ |\\ CHOH\\ |\\ CH_2Cl\end{array} \rightarrow \begin{array}{c}CH_2Cl\\ |\\ CO\\ |\\ CH_2Cl\end{array} \rightarrow \begin{array}{l}CH_2Cl\\ |\\ C<^{OH}_{CN}\\ |\\ CH_2Cl\end{array} \rightarrow \begin{array}{l}CH_2Cl\\ |\\ C<^{OH}_{CO_2H}\\ |\\ CH_2Cl\end{array}$$

$$\rightarrow \begin{array}{l}CH_2CN\\ |\\ C<^{OH}_{CO_2H}\\ |\\ CH_2CN\end{array} \rightarrow \begin{array}{l}CH_2CO_2H\\ |\\ C<^{OH}_{CO_2H}\\ |\\ CH_2CO_2H.\end{array}$$

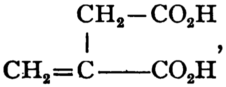
Citric acid crystallizes from water in rhombic prisms which contain one molecule of water of crystallization. It is soluble in three-fourths of its weight of cold water. The anhydrous acid melts at 153°.

If citric acid is heated to 175° it loses water, and gives *aconitic* acid,



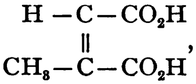
$$\begin{array}{l}\mathrm{CH_2CO_2H}\\ |\\ \mathrm{C-CO_2H.}\\ \|\\ \mathrm{CHCO_2H}\end{array}$$

At a higher temperature the aconitic acid decomposes, giving *itaconic acid*,



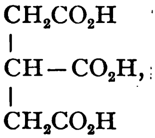
$$\begin{array}{rl} & \mathrm{CH_2-CO_2H}\\ & |\\ \mathrm{CH_2=} & \mathrm{C——CO_2H}\end{array},$$

and also, by rearrangement, *citraconic acid*,



$$\begin{array}{rl}\mathrm{H-} & \mathrm{C-CO_2H}\\ & \|\\ \mathrm{CH_3-} & \mathrm{C-CO_2H}\end{array},$$

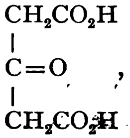
or their anhydrides. Aconitic acid can be reduced to tricarballylic acid,



$$\begin{array}{l}\mathrm{CH_2CO_2H}\\ |\\ \mathrm{CH-CO_2H,}\\ |\\ \mathrm{CH_2CO_2H}\end{array}$$

by sodium amalgam.

When warmed on the water-bath with concentrated sulphuric acid, citric acid is decomposed into formic acid and *acetone dicarboxvlic acid*,



$$\begin{array}{l}\mathrm{CH_2CO_2H}\\ |\\ \mathrm{C=O}\quad ,\\ |\\ \mathrm{CH_2CO_2H}\end{array}$$

the formic acid decomposing, further, into carbon monoxide and water.

With manganese dioxide and sulphuric acid it is oxidized to acetone and carbon dioxide. (Why? See pp. 217 and 351.)

Both citric acid and its salts are extensively used. A concentrated solution of the neutral ammonium salt, $(NH_4)_3C_6H_5O_7$, is used in the analysis of fertilizers to dissolve "citrate-soluble" (formerly called "reverted") phosphates. A mixture of ferric ammonium citrate,

$$(FeC_6H_5O_7 + (NH_4)_2C_6H_6O_7 \text{ or } FeC_6H_5O_7 + NH_4C_6H_7O_7),$$

and potassium ferricyanide is used in the preparation of the ordinary "blue print" paper, the reducing action of the citric acid converting the iron to the ferrous state under the action of sunlight.

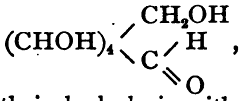
At least *eleven* acids of the formula,

$$\begin{array}{l} CH(OH)-CO_2H \\ | \\ CH(OH) \\ | \\ CH(OH) \\ | \\ CH(OH)-CO_2H \end{array},$$

are known. These differ, apparently, in the relation between the asymmetric carbon atoms which they contain. The general structure has been established by the reduction of most of them to adipic acid $(CH_2)_4(CO_2H)_2$.

The most important of these acids are saccharic and mucic acids.

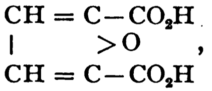
Saccharic Acid exists in the two optically active forms and in the racemic form. The *dextrosaccharic acid* is formed by the oxidation of cane-sugar, milk-sugar, raffinose, starch, or glucose by means of nitric acid. As all of these substances yield *d*-glucose,



as one product of their hydrolysis with acids, *d*-saccharic acid must be considered as the normal oxidation product of that body.

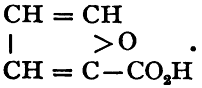
Mucic Acid is formed by the oxidation of some gums, raffinose or melitose, milk-sugar, dulcite, quercite or galactose by nitric acid. As all of these substances except quercite give galactose by hydrolysis, or may be prepared from galactose,* mucic acid is to be considered as the normal oxidation product of that substance. Galactose differs from glucose only in configuration, the structural formulae being otherwise identical.

Both saccharic and mucic acids and all isomeric acids, which differ from them only in configuration, give *dehydromucic acid*,



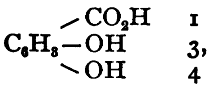
$$\begin{array}{l} CH = C-CO_2H \\ | \qquad\quad >O \quad , \\ CH = C-CO_2H \end{array}$$

when heated to 150° with concentrated hydrochloric acid. When heated to a higher temperature, this decomposes into carbon dioxide and pyromucic acid,



$$\begin{array}{l} CH = CH \\ | \qquad\quad >O \quad . \\ CH = C-CO_2H \end{array}$$

Protocatechuic Acid (3.4 dihydroxybenzoic acid),



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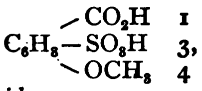
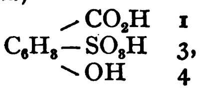
* Dulcite is formed by the reduction of galactose.

is prepared from vanillin by fusion with caustic potash (p. 186). It is also formed by fusing *sulphanisic acid*,



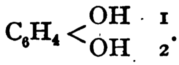
$$C_6H_3\begin{array}{l}\diagup CO_2H\\ -SO_3H\\ \diagdown OCH_3\end{array}\quad\begin{array}{l}1\\ 3,\\ 4\end{array}$$

or *p-cresol sulphonic acid*,



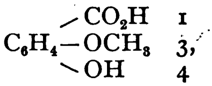
$$C_6H_3\begin{array}{l}\diagup CO_2H\\ -SO_3H\\ \diagdown OH\end{array}\quad\begin{array}{l}1\\ 3,\\ 4\end{array}$$

with caustic potash. It crystallizes in monoclinic needles, which melt at 199°, with decomposition. The acid decomposes, on distillation, into carbon dioxide and pyrocatechol,



$$C_6H_4<\begin{array}{l}OH\\ OH\end{array}\quad\begin{array}{l}1\\ 2.\end{array}$$

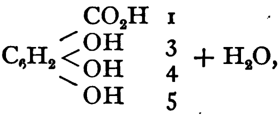
Protocatechuic acid can be prepared from vanillin (p. 186), asafoetida, myrrh, and a considerable number of other natural substances. Its methyl ether,



$$C_6H_3\begin{array}{l}\diagup CO_2H\\ -OCH_3\\ \diagdown OH\end{array}\quad\begin{array}{l}1\\ 3,\\ 4\end{array}$$

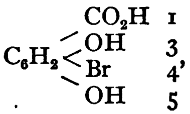
is called *vanillic acid.*

Gallic Acid,



$$C_6H_2\begin{array}{l}CO_2H\\ \diagup OH\\ <OH\\ \diagdown OH\end{array}\quad\begin{array}{l}1\\ 3\\ 4\\ 5\end{array} + H_2O,$$

is prepared by boiling tannic acid with dilute acids. It is also formed by fusing *dioxybrombenzoic acid*,



$$C_6H_2\begin{array}{l}CO_2H\\ \diagup OH\\ <Br\\ \diagdown OH\end{array}\quad\begin{array}{l}1\\ 3\\ 4,\\ 5\end{array}$$

with caustic potash. Gallic acid melts with decomposition at 220°–240°. It decomposes, on distillation, into carbon dioxide and pyrogallol (p. 166).

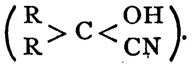
Tannin, $C_{14}H_{10}O_9 + 2\ H_2O$, is found in oak bark, sumach, tea-leaves, canaigre root, and a great variety of other substances. It has been prepared by heating gallic acid with phosphorus oxychloride:

$$\underset{\text{Gallic acid.}}{2\ C_7H_6O_5} - H_2O = \underset{\substack{\text{Tannin, or}\\ \text{Tannic acid.}}}{C_{14}H_{10}O_9}$$

Tannin forms an insoluble compound with albumin; also with the corium of animal skins, converting them into leather.

General Methods of Preparing Hydroxy Acids.

The general methods of preparing hydroxy acids are essentially the same as those for preparing alcohols (p. 161). The only methods of preparation peculiar to the acids are the Reimer-Tiemann reaction, using phenol and carbon tetrachloride; Kolbe's reaction of a sodium or potassium phenolate and carbon dioxide; the formation of a lactone from a β-γ-unsaturated acid by boiling with dilute sulphuric acid; the oxidation of a tertiary hydrogen atom; the reduction of the unsymmetrical chloride of an "inner" anhydride; and the preparation of α-hydroxy acids from aldehydes and ketones, through the cyanhydrins,



$$\left(\begin{matrix}R\\R\end{matrix}>C<\begin{matrix}OH\\CN\end{matrix}\right).$$

General Properties of Hydroxy Acids.

The general properties of hydroxy acids are, in part, merely the same as those of alcohols. Thus primary hydroxyl groups may be oxidized to aldehyde and carboxyl groups. Secondary hydroxyl groups may be oxidized to ketone groups. If the resulting ketone group is in the α-position, further oxidation gives an acid with one less carbon atom; if in the β-position, the ketonic acid is unstable (p. 351), and loses carbon dioxide with formation of a ketone. As γ-hydroxy acids readily form lactones, it is usually necessary to convert them into esters before oxidation.

Besides the oxidation to ketonic acids, which can sometimes be effected, α-hydroxy acids may be oxidized to aldehydes or ketones and carbon dioxide by means of lead peroxide or manganese dioxide and sulphuric acid.

α-Hydroxy acids do not form lactones or inner anhydrides, but do form anhydrides from two molecules of the acid, such anhydrides containing a ring of four carbon and two oxygen atoms. If, however, the α-carbon atom bears no hydrogen, such anhydrides are not formed, but the acid may distill without decomposition.

β-Hydroxy acids very rarely form lactones. They lose water easily, and give α-β-unsaturated acids.

γ-Hydroxy acids readily form inner anhydrides, called lactones. δ-Lactones are much less common, and very few ε-lactones have been prepared.

Phosphorus trichloride, phosphorus pentachloride, and the tribromide and pentabromide, when they act upon hydroxy acids, replace the alcoholic as well as the carboxyl hydroxyl with chlorine or bromine.

$$\underset{\text{Lactic acid.}}{CH_3CH(OH)CO_2H} + 2\,PCl_5$$
$$= \underset{\substack{\text{Chloride of }\alpha\text{-chlor-}\\ \text{propionic acid.}}}{CH_3CHClCOCl} + 2\,POCl_3 + 2\,HCl.$$

In many cases the hydroxyl group in aliphatic or alicyclic *

---

* Derivations of cyclopropane, cyclobutane, etc., are called "alicyclic" compounds, because their general chemical conduct resembles that of the aliphatic, and not that of the aromatic compounds.

compounds can be replaced by merely treating them with strong hydrochloric or hydrobromic acid.

By heating with hydriodic acid, aliphatic or alicyclic hydroxy acids may be reduced, the hydroxyl being replaced by hydrogen:

$$CH_3CH(OH)CO_2H + 2HI = CH_3CH_2CO_2H + I_2 + H_2O.$$

Ortho-hydroxy acids, in the aromatic series, give a violet color with ferric chloride, meta- and para-hydroxy acids do not.

Unsaturated hydroxy acids of the general formula,

$$R-C(OH) = CH-CO_2H,$$

also give a violet color with ferric chloride, while the tautomeric form, $R-CO-CH_2CO_2H$, when sufficiently stable to have an independent existence, does not do this. The esters of these acids conduct themselves in a similar manner.

Laboratory Exercises.

Prepapation of the following: —

1. Glycocoll.
2. Glycolid.
3. Isocaprolactone, starting with amyl alcohol.
4. Salicylic acid, two ways.
5. Parahydroxybenzoic acid.
6. Phthalid.
7. Diacetyl derivative of the diethyl ester of tartaric acid.
8. Mandelic acid.

CHAPTER XVI.

KETONIC AND ALDEHYDE ACIDS.

As has already been pointed out, the ketonic and aldehyde acids are isomeric with the unsaturated hydroxy acids. So far as the two classes of compounds are "tautomeric," the unsaturated hydroxy acids will also be discussed in this chapter.

Glyoxylic Acid, $CH(OH)_2CO_2H$, which is to be considered as the simplest aldehyde acid, has already been considered (p. 325).

Pyroracemic Acid (propanonic acid), CH_3COCO_2H, is formed by the oxidation of lactic acid, $CH_3CHOHCO_2H$, by boiling *a*-dichlorpropionic acid, $CH_3CCl_2CO_2H$, with water, by the saponification of acetyl cyanide, CH_3COCN (from acetyl chloride and silver cyanide) with hydrochloric acid, and by distilling racemic or tartaric * acid, either by themselves, or mixed with acid potassium sulphate.

Pyroracemic acid is a liquid which boils with some decomposition at 165°. It solidifies at a low temperature, and melts at 9°. It mixes in all proportions with water, alcohol, and ether.

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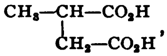
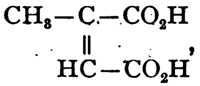
* Pyroracemic acid must not be confused with ***methyl succinic acid,***



$$\begin{array}{l} CH_3\text{—}CH\text{—}CO_2H \\ \qquad\;\; | \\ \qquad CH_2\text{—}CO_2H \end{array},$$

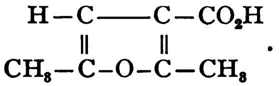
which is also formed by the distillation of tartaric or racemic acid, and which has, unfortunately, been called ***pyrotartaric acid.***

When heated by itself, pyroracemic acid gives, at 170°, acetic acid, carbon dioxide, methyl succinic acid (pyrotartaric acid), citraconic acid,



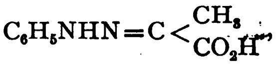
$$\begin{array}{l} CH_3-C-CO_2H \\ \qquad\ \ \| \\ \quad\ HC-CO_2H \end{array},$$

and uvinic acid (dimethylfurane carboxylic acid),



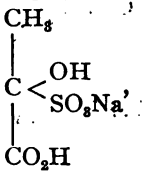
The formation of the last three acids illustrates the tendency of the acid to polymerize or condense with itself. It also condenses readily with many other substances. Thus, with benzene and concentrated sulphuric acid it gives *diphenylpropionic acid*, $CH_3C(C_6H_5)_2CO_2H$, and similar condensation products with phenol and other aromatic compounds.

Pyroracemic acid, as a ketone, gives a phenyl hydrazone,



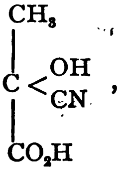
$$C_6H_5NHN{=}C{<}\begin{smallmatrix} CH_3 \\ CO_2H \end{smallmatrix},$$

an oxime, $CH_3C(NOH)CO_2H$, a double compound with acid sodium sulphite,



$$\begin{array}{l} CH_3 \\ | \\ C{<}\begin{smallmatrix} OH \\ SO_3Na \end{smallmatrix}, \\ | \\ CO_2H \end{array}$$

and a cyanhydrin,

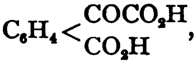


$$\begin{array}{l} CH_3 \\ | \\ C{<}\begin{smallmatrix} OH \\ CN \end{smallmatrix}, \\ | \\ CO_2H \end{array}$$

with hydrocyanic acid.

Phenylglyoxylic Acid, $C_6H_5COCO_2H$, is prepared by the oxidation of acetophenone, $C_6H_5COCH_3$, with a cold, strongly alkaline solution of potassium permanganate. The name represents it as a derivative of glyoxylic acid, $HCO-CO_2H$. It can also be prepared from benzoyl cyanide, C_6H_5COCN. Phenylglyoxylic acid melts at 66°. It is easily soluble in water and ether, but insoluble in carbon disulphide. It decomposes, on heating, chiefly into benzoic acid and carbon monoxide, but partly into benzaldehyde and carbon dioxide. It is easily oxidized to benzoic acid by manganese dioxide and sulphuric acid, resembling, in this, oxalic acid, to which it is related.

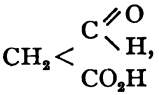
Phthalonic Acid,



$$C_6H_4<\begin{matrix}COCO_2H\\CO_2H\end{matrix},$$

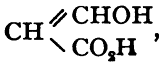
is prepared by the oxidation of naphthalene with potassium permanganate in an alkaline solution (p. 261).

Formyl Acetic Acid,



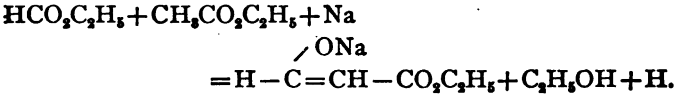
$$CH_2<\begin{matrix}C\begin{matrix}/\!/O\\ \backslash H,\end{matrix}\\CO_2H\end{matrix}$$

or β-hydroxyacrylic acid,



$$CH\begin{matrix}/\!/CHOH\\ \backslash CO_2H\end{matrix},$$

is not known in the free state. Its ethyl ester is formed by the action of sodium upon a mixture of the ethyl esters of formic and acetic acid,



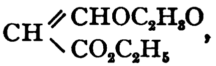
$$HCO_2C_2H_5+CH_3CO_2C_2H_5+Na$$

$$=H-\overset{/ONa}{C}=CH-CO_2C_2H_5+C_2H_5OH+H.$$

Sodium salt of formyl acetic ester.

The reaction is similar to that for the preparation of acetoacetic ester, which will be discussed below.

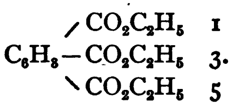
When the sodium salt is treated with acetyl chloride an acetyl derivative,



$$CH\begin{cases}\!/\!\!/\,CHOC_2H_3O\\ \diagdown\,CO_2C_2H_5\end{cases},$$

is formed, which has been shown to be an unsaturated compound by the fact that it adds two atoms of bromine directly. This indicates that the sodium salt, at least, has the "enol" form (pp. 205 and 349).

Fomyl acetic ester is very unstable, condensing spontaneously in its solutions, to trimesitic ester,



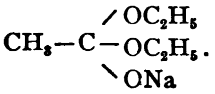
$$C_6H_3\begin{cases}/\,CO_2C_2H_5 & 1\\ -\,CO_2C_2H_5 & 3.\\ \diagdown\,CO_2C_2H_5 & 5\end{cases}$$

Acetoacetic Acid, $CH_3COCH_2CO_2H$,

or $CH_3C(OH)=CH-CO_2H$,

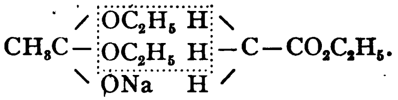
is not known in the free state otherwise than in solution. It is found in the urine of persons suffering from diabetes, and sometimes in those suffering from fevers. Its presence is believed always to be pathological.

Acetoacetic Ester. — The *ethyl ester*, $CH_3COCH_2CO_2C_2H_5$ or $CH_3C(OH)=CH-CO_2C_2H_5$, is formed by the action of metallic sodium upon acetic ester. It is believed that the sodium at first acts upon a trace of alcohol present in the ester to form sodium ethylate, and that the latter adds itself to the acetic ester to form the compound,



$$CH_3-C\begin{cases}/\,OC_2H_5\\ -\,OC_2H_5.\\ \diagdown\,ONa\end{cases}$$

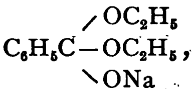
This compound then condenses with another molecule of acetic ester thus:



$$CH_3C\begin{matrix}\diagup \\ - \\ \diagdown\end{matrix}\boxed{\begin{matrix}OC_2H_5 & H \\ OC_2H_5 & H\end{matrix}}\begin{matrix}\diagdown \\ - \\ \diagup\end{matrix}C-CO_2C_2H_5.$$
$$\qquad ONa \quad H$$

This reaction, and many others of a similar character which have a bearing upon it, have been very carefully studied by many different chemists; and both the reaction and the structure of the acetoacetic ester have been subjects of much controversy. Prominent chemists still hold divergent views upon some of the questions involved. The explanation given is that of Claisen, and depends chiefly on the facts:

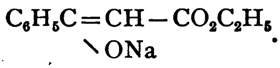
1. That addition compounds of the character supposed have been prepared, as, for instance, the compound,



$$C_6H_5C\begin{matrix}\diagup OC_2H_5 \\ -OC_2H_5, \\ \diagdown ONa\end{matrix}$$

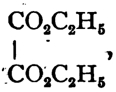
from benzoic ester and sodium ethylate.

2. That this addition compound reacts with acetic ester to form sodium benzoyl acetic ester,



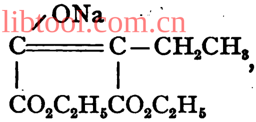
$$\begin{matrix}C_6H_5C=CH-CO_2C_2H_5 \\ \diagdown ONa\end{matrix}$$

3. That esters condense in this manner only when they have at least two hydrogen atoms combined with the carbon atom adjacent to the carboxethyl ($CO_2C_2H_5$) group. Thus oxalic ester,

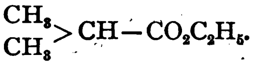


$$\begin{matrix}CO_2C_2H_5 \\ | \\ CO_2C_2H_5\end{matrix},$$

condenses with normal butyric ester giving the compound,



but it will not condense with isobutyric ester,



$$\begin{matrix} CH_3 \\ CH_3 \end{matrix} > CH - CO_2C_2H_5.$$

Acetoacetic ester is a colorless liquid with a pleasant odor. It boils with slight decomposition at 180°. It gives a violet color with ferric chloride, recalling the color given by salicylic and other orthohydroxy aromatic acids. In cases where derivatives of acetoacetic acid have been prepared in both the ketone ($R - COCH_2CO_2C_2H_5$) and "enol"

$$(R - C(OH) = CHCO_2C_2H_5)$$

form, it has been found that only the latter gives the reaction with ferric chloride. This justifies the conclusion that the free acetoacetic ester exists, at least in part, in the "enol" form.* The resemblance to phenols is further shown by the solubility of the ester in solutions of sodium or potassium hydroxide and its precipitation from such solutions by carbonic acid.

Acetoacetic ester also gives reactions in which it behaves as a ketone. It forms a double compound with acid sodium sulphite, and decomposes into acetone, carbon dioxide, and alcohol when boiled with dilute acids.

Many other reactions can be interpreted by either the ketone or enol formula. The more common opinion, at present,

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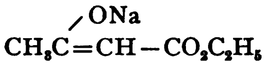
* Schiff has given some evidence which seems to show that the ester sometimes consists exclusively of the "enol" form. *Ber. d. chem. Ges.*, 31, 601, 1388. See also Traube, *Ibid*, 29, 1715.

is that in the metallic derivatives the metal is combined with oxygen; thus, that sodium acetoacetic ester is



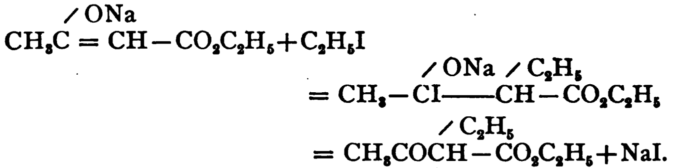
$$CH_3\overset{\diagup ONa}{C}=CH-CO_2C_2H_5$$

and not

$$CH_3CO-CHNaCO_2C_2H_5,$$

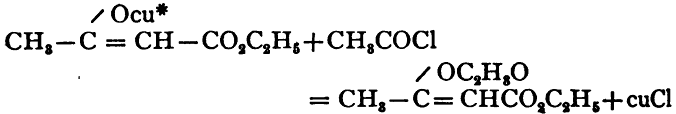
though the latter formula is still used, often, perhaps, without intending to express an opinion as to the real structure. (For the effect of solvents on tautomeric compounds see Bamberger, *Ber. d. chem. Ges.* 34, 2003.) It has been found that in the presence of water or alcohol the transformation from the ketone to the enol form, or *vice versa*, takes place much more easily than in the presence of ligroin, chloroform, or benzene.

Condensations with Acetoacetic Ester.—When the metallic derivatives of acetoacetic ester are treated with halogen compounds, derivatives are obtained in which the radical sometimes unites with carbon and in other cases with oxygen. As types of the two classes of reactions may be given the following:



$$CH_3\overset{\diagup ONa}{C} = CH-CO_2C_2H_5+C_2H_5I$$
$$= CH_3-\overset{\diagup ONa}{C}I\text{——}\overset{\diagup C_2H_5}{CH}-CO_2C_2H_5$$
$$= CH_3CO\overset{\diagup C_2H_5}{CH}-CO_2C_2H_5+NaI.$$

Ethyl acetoacetic ester.



$$CH_3-\overset{\diagup Ocu^*}{C} = CH-CO_2C_2H_5+CH_3COCl$$
$$= CH_3-\overset{\diagup OC_2H_3O}{C}= CHCO_2C_2H_5+cuCl$$

O-acetyl-acetoacetic ester.

---

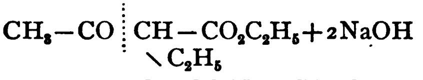
* By cu is meant the half atom of copper.

Reactions of the second type are interesting as furnishing evidence of the structure of the salts of acetoacetic ester, but those of the first type are of much greater practical importance. By means of similar reactions compounds of the general formula $CH_3COCHRCO_2C_2H_5$ and

$$CH_3COCRR'CO_2C_2H_5$$

have been prepared in very great variety. The synthesis is similar to the malonic ester synthesis (p. 252), and by means of the "acid decomposition" it may lead to the same products. It is worthy of notice that when both hydrogen atoms of the methylene (CH_2) group have been replaced, the product is no longer soluble in alkalies, because it is necessarily of the "ketone form."

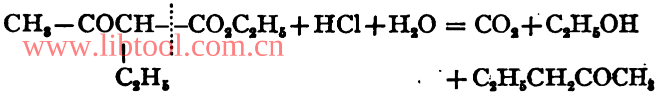
Acid Decomposition. — Boiling with alkalies or acids saponifies acetoacetic ester, or its derivatives, but the resulting acids are unstable and usually undergo a further decomposition. In alkaline solutions, in general, though by no means always, the acid undergoes the "acid decomposition," losing the acetyl group, and giving acetic acid or a derivative of acetic acid:



$$CH_3-CO\,\vdots\,\underset{\diagdown C_2H_5}{CH}-CO_2C_2H_5+2NaOH$$
$$= CH_3CO_2Na+C_2H_5OH+H_2O+\underset{\text{Sodium butyrate.}}{C_2H_5CH_2CO_2Na.}$$

Ketonic Decomposition. — The acid decomposition gives the same product which would be obtained by the decomposition of the bibasic acid resulting from the malonic ester synthesis (p. 252); and, in general, malonic ester or cyanacetic ester is to be preferred for syntheses of this kind.

When boiled with acids, usually with hydrochloric or sulphuric acid, acetoacetic ester and its derivatives undergo "ketonic decomposition," and give a ketone:



$$CH_3-\underset{\underset{C_2H_5}{|}}{COCH}-\vdots-CO_2C_2H_5+HCl+H_2O=CO_2+C_2H_5OH+C_2H_5CH_2COCH_3$$

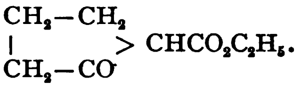
Propyl methyl ketone.

In some cases, when a clean "acid decomposition" cannot be secured, and the substance sought is the acid and not the ketone, the latter may be oxidized to the acid by means of sodium hypochlorite or hypobromite (p. 199):

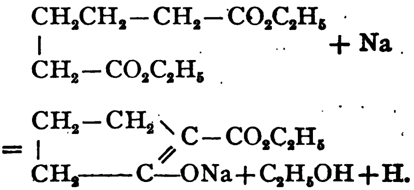
$$C_2H_5CH_2-COCH_3+3NaBrO=$$
$$C_2H_5CH_2CO_2Na+CHBr_3+2\ NaOH.$$

A considerable number of synthetic processes closely analogous to that of the preparation of acetoacetic ester are known. Among the most interesting of these are several which give rise to cyclic compounds. As has been noticed so often in other cases, only those reactions which result in rings of five or six carbon atoms take place readily and with satisfactory yields.

Carboxethyl Cyclopentanone,

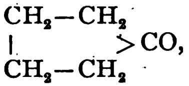


When sodium, in the form of wire, is introduced into a mixture of adipic ester and toluene, and the mixture is heated, condensation to a cyclic compound takes place:



The free carboxethyl cyclopentanone is obtained from the sodium salt on the addition of dilute sulphuric acid. It boils with slight decomposition at 220°, or at 110° under a pressure of 15 mm. The sodium salt is quite difficultly soluble in water. The copper salt is also difficultly soluble, even in the presence of some acetic acid. This indicates the decided acid character of the ester, and that it exists, largely at least, in the "enol" form.

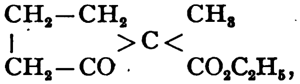
When the ester is saponified with alkalies, adipic acid is regenerated (acid decomposition). When boiled with acids, it is decomposed into carbon dioxide and cyclopentanone,



$$\begin{array}{l} CH_2-CH_2 \\ | \qquad\qquad > CO, \\ CH_2-CH_2 \end{array}$$

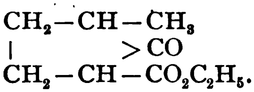
(ketonic decomposition).

When the sodium salt of the ester is treated with methyl iodide, 2-*methyl-2-carboxethyl-cyclopentanone*,



$$\begin{array}{l} CH_2-CH_2 \qquad CH_3 \\ | \qquad\qquad >C< \\ CH_2-CO \qquad CO_2C_2H_5, \end{array}$$

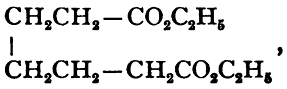
is formed; and this gives, by saponification, α-methyladipic acid. The ethyl ester of the latter may be condensed, in the same manner as the adipic ester, to 5-*methyl-2-carboxethyl cyclopentanone*,



$$\begin{array}{l} CH_2-CH-CH_3 \\ | \qquad\qquad > CO \\ CH_2-CH-CO_2C_2H_5. \end{array}$$

The hydrogen adjacent to the carboxethyl group in this compound may also be replaced by methyl. These facts illustrate some of the syntheses which may be effected with compounds of this character.

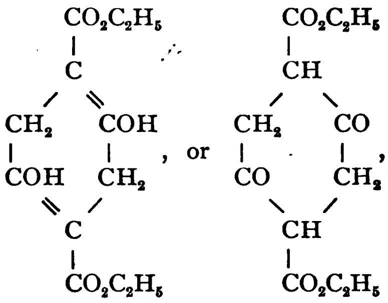
Carboxethyl Cyclohexanone and its derivatives can be obtained from *pimelic ester*,



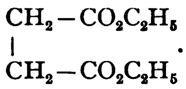
$$\begin{array}{l} CH_2CH_2-CO_2C_2H_5 \\ | \\ CH_2CH_2-CH_2CO_2C_2H_5 \end{array},$$

in a similar manner.

Succinylosuccinic Ester,



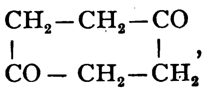
is formed as a sodium salt when sodium wire and a few drops of alcohol are allowed to act on succinic ester,



$$\begin{array}{l} CH_2-CO_2C_2H_5 \\ | \\ CH_2-CO_2C_2H_5 \end{array}.$$

In this case two molecules of the ester condense together. Succinylosuccinic ester crystallizes in yellowish or greenish leaflets, which melt at 127°. It dissolves readily in alkalies, and gives, with ferric chloride, an onion red color, indicating that it exists in the enol form.

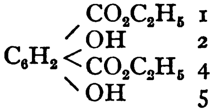
When boiled with dilute sulphuric acid it gives 1.4 cyclohexanedion,



$$\begin{array}{l} CH_2-CH_2-CO \\ |\qquad\qquad\quad | \\ CO-CH_2-CH_2 \end{array},$$

by ketonic decomposition.

When treated with bromine, it is converted quantitatively into *dioxyterephthalic ester*,



$$C_6H_2\left\langle\begin{array}{ll} CO_2C_2H_5 & 1\\ OH & 2\\ CO_2C_2H_5 & 4\\ OH & 5\end{array}\right. .$$

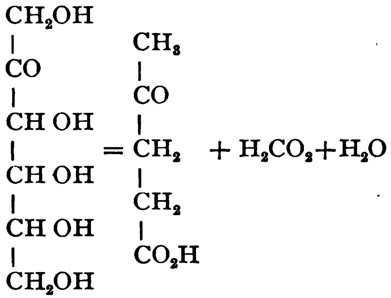
This conversion is of especial interest, as it disproves the Ladenburg formula for benzene (p. 101). (Baeyer, *Ber. der chem. Ges.* 19, 1798.)

Levulinic Acid (4-pentanonic acid),

$$CH_3COCH_2CH_2CO_2H,$$

is the simplest and best-known γ-ketonic acid. It is prepared by heating starch, levulose, cane sugar, and some other carbohydrates with dilute hydrochloric acid:

$$\underset{\text{Levulose.}}{C_6H_{12}O_6} = \underset{\text{Levulinic acid.}}{C_5H_8O_3} + \underset{\text{Formic acid.}}{HCO_2H} + H_2O,$$

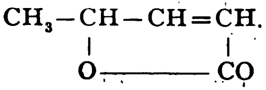


$$\begin{array}{l} CH_2OH\\ |\\ CO\\ |\\ CH\,OH\\ |\\ CH\,OH\\ |\\ CH\,OH\\ |\\ CH_2OH\end{array} = \begin{array}{l} CH_3\\ |\\ CO\\ |\\ CH_2\\ |\\ CH_2\\ |\\ CO_2H\end{array} + H_2CO_2 + H_2O$$

The reaction is accomplished by an internal reduction and oxidation, which is suggestive, but which is very little understood. The reaction is accompanied by others which cause the complete decomposition of a large part of the sugar; and the yield is small, only ten or fifteen per cent of the weight of sugar used.

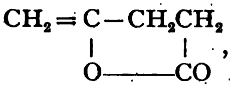
Levulinic acid melts at 33°, boils with but slight decomposition at 239°, and with no decomposition at 149° under a pressure of 15 mm. The difference in stability between the β- and γ-ketonic acids is very noticeable and remarkable.

When levulinic acid is kept for some time at its boiling point, it is gradually converted into two isomeric anhydrides, called angelicalactones. The α-anhydride,



$$\begin{array}{ccccccc} CH_3 & - & CH & - & CH & = & CH. \\ & & | & & & & | \\ & & O & - & - & - & CO \end{array}$$

boils at 167°; the β-anhydride,



$$\begin{array}{ccccc} CH_2 & = & C & - & CH_2CH_2 \\ & & | & & | \quad , \\ & & O & - & CO \end{array}$$

at 208°. The α-anhydride solidifies at a low temperature, and melts at 18°. Each anhydride unites directly with two atoms of bromine, the β-anhydride combining with the bromine less readily than the α-anhydride.

Laboratory Exercises.

Preparation of the following:

1. Acetoacetic ester.
2. Phenylglyoxylic acid.
3. Phthalonic acid.
4. Condensation of acetoacetic ester with benzyl chloride and preparation of hydrocinnamic acid.
5. Succinylosuccinic ester.
6. Levulinic acid.

CHAPTER XVII.

CARBOHYDRATES. GLUCOSIDES.

THE specific rotations given below are for a 10% aqueous solution of the anhydrous sugar with sodium light.*

PENTOSES. $C_5H_{10}O_5$.

	[α]*D*.		[α]*D*.
l-Arabinose	— 83°	**d-Xylose**	+ 18.8°
d-Arabinose	+ 105.1°	**l-Xylose**	— 18.05°
dl-Arabinose	0		

HEXOSES, $C_6H_{12}O_6$.

A-ALDOHEXOSES.		REDUCTION PRODUCT.	OXIDATION PRODUCT.
d-Glucose	52.7°	**d-Sorbite**	**d-Saccharic acid.**
l-Glucose	— 51.4°	——	**l-Saccharic acid.**
dl-Glucose	0	——	**dl-Saccharic acid.**
d-Gulose	——	——	**d-Saccharic acid.**
l-Gulose	——	**l-Sorbite**	**l-Saccharic acid.**
dl-Gulose	0	——	**dl-Saccharic acid.**
d-Galactose	+ 81.5°	**Dulcite**	**Mucic acid.**
l-Galactose	— 73.6°	**Dulcite**	**Mucic acid.**
dl-Galactose	0	——	**Mucic acid.**
d-Mannose	+ 14.25°	**d-Mannite**	**d-Mannosaccharic acid.**
l-Mannose	——	**l-Mannite**	**l-Mannosaccharic acid.**
dl-Mannose	0	**dl-Mannite**	**dl-Mannosaccharic acid.**
B-KETOHEXOSES.			
d-Fructose (l′)	——	**Mannite and Sorbite**	
l-Fructose (levulose) (d′)	— 93.°		
dl-Fructose (α-acrose)	0	**dl-Mannite**	
l-Sorbinose	——	**Sorbite**	
dl-Inosite (hexahydroxy-cyclohexane)	0		
Rhamnose ($C_{12}H_{10}O_5$)	+ 8.4°		

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* Some years ago Fischer (Ber. 23, 371) proposed the use of the prefixes *d* and *l* to indicate not the actual right- or left-handed rotation of the compound but the genetic relationship to other compounds. Thus the natural fructose, which is laevo-rotatory, was called *d*-fructose because of its relation to *d*-glucose. More recently (Ber. 40, 102), in reply to a proposal of Rosanoff (*J. Am. Chem. Soc.* 28, 114), which appeared to him unsuitable, Fischer has proposed the designations *d′* and *l′* for those cases where the rotation does not correspond to the genetic relationships of the compound. Thus ordinary fructose is called *d′*-fructose.

In this nomenclature the prefix *d* indicates, of course, a compound which is both dextro-rotatory and also belongs to the dextro-rotatory group. In this book the prefixes *d* and *l* are used exclusively for the actual direction of the rotation, but Fischer's designations, *d′* and *l′*, are also given in a few cases. For racemic compounds the prefix *dl* is used.

HEPTOSES, $C_7H_{14}O_7$.

Rhamnohexose, α-Glucoheptose, β-Glucoheptose, d-Mannoheptose, l-Mannoheptose, i-Mannoheptose,

OCTOSES, $C_8H_{16}O_8$.

Rhamnoheptose, α-Glucose, d-Mannooctose.

NONOSES, $C_9H_{18}O_9$.

Glucononose, Mannononose.

DISACCHARIDES, $C_{12}H_{22}O_{11}$.

	$[\alpha]_D$.	PRODUCTS OF HYDROLYSIS.
Maltose	+ 137.04°	**Glucose.**
Isomaltose	+ 69.°(?)	**Glucose.**
Melibiose	+ 129.38°	**Glucose, galactose.**
Lactose (Milk sugar)	52.5°	**Glucose, galactose.**
Saccharose (Cane Sugar)	+ 66.54°	**Glucose, fructose.**
Trehalose	+ 199°	**Glucose.**
Turanose	——	**Glucose.**

TRISACCHARIDES, $C_{18}H_{32}O_{16}$.

Raffinose (Melitose, Melitriose)	104.5°	**Glucose, turanose.**
Melezitose	88.5°	**Fructose, melibiose.**

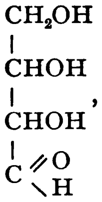
Dextrin	**Amylodextrin**	193.4°	**Glucose.**
	Acroödextrin	192.°	
	Erythrodextrin	196.°	
	Maltodextrin	181°–183°	
Inulin		— 36.57°	**Fructose.**
Arabin		— 98.5°	**Arabinose.**
Xylan		— 84.°	**Xylose.**
Lactosin		+ 211.7°	**Galactose and (?)**
α-Amylan		αj = — 24°	**Glucose.**
β-Amylan		αj = — 73°	**Glucose (?).**
Starch		+	**Glucose.**
Cellulose		— (?)	**Glucose.**

The name "carbohydrate" has been given to a class of bodies, mostly of vegetable origin, which contain carbon, hydrogen, and oxygen, and in which the proportion between the hydrogen and oxygen is the same as in water. The group includes starch and sugar, the most important non-nitrogenous compounds in the food of men, and cellulose, an important article of diet for herbivorous animals.

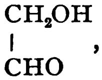
A very large proportion of the natural carbohydrates have molecules containing six, or a multiple of six, carbon atoms. Some natural gums are known, however, which have in their molecules a multiple of five carbon atoms; and these yield, by hydrolysis, sugars with molecules containing but five carbon atoms. Sugars containing larger and smaller numbers of carbon atoms have been prepared synthetically.

In composition, formaldehyde, CH_2O, might, in some sense, be considered as the simplest carbohydrate, but has few of the properties characteristic of the carbohydrates, and is never classed with them. The theory that formaldehyde is the first reduction product of carbonic acid in plants, and that starch is formed by its polymerization (Baeyer *Ber. d. chem. Ges.* 3, 63) has, however, much in its favor.

Tetrose,



may, perhaps, be considered as the simplest sugar, though glycollic aldehyde,



$$\begin{array}{l} CH_2OH \\ | \\ CHO \end{array},$$

and glyceric aldehyde,

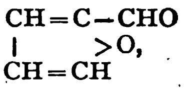
$$CH_2OH,CHOH,CHO,$$

might, from the definition, be termed carbohydrates and called *diose* and *triose.* Tetrose is formed by the polymerization of glycol aldehyde, when its solution, containing one per cent of sodium hydroxide, is allowed to stand at 0° for fifteen hours.

Arabinose and Xylose,

$$CH_2OHCHOHCHOHCHOHCHO,$$

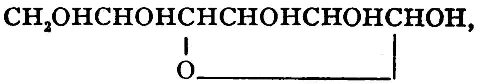
have the same structure, but different configurations, and, so, different rotatory power, and different properties in other respects. Each gives *furfural,*



when heated with dilute hydrochloric or sulphuric acid. This indicates, very clearly, the structure of the sugars. The reaction is closely analogous to the formation of dehydromucic acid from saccharic and mucic acids (p. 339). As furfural can be readily determined quantitatively, its formation is made the basis for the determination of xylose and of *xylan,* which yields xylose by hydrolysis with dilute acids.

Both arabinose and xylose reduce Fehling's solution. Neither arabinose nor xylose can be fermented with pure yeast. *Bacillus enthaceticus,* however, causes the fermentation of arabinose with formation of hydrogen, carbon dioxide, ethyl alcohol, and acetic acid.

***d*-Glucose (Grape sugar, dextrose, starch sugar),**



$$CH_2OHCHOHCHCHOHCHOHCHOH,$$

is the most important of the *hexoses,* or sugars containing six carbon atoms in the molecule. Glucose is found widely disseminated in the vegetable kingdom, usually associated with an equivalent amount of fructose. Starch, dextrin, and maltose are converted, almost quantitatively, into glucose by the hydrolysis effected by heating with dilute acids. It is also a partial product of the hydrolysis of cane sugar, milk sugar, raffinose, and several other disaccharides and polysaccharides. Glucose is secreted in the urine in the disease known as *diabetes mellitus*, sometimes in very considerable quantities.

Glucose is most easily prepared pure from cane sugar, which is very easily hydrolyzed by the action of dilute acids, yielding glucose and fructose in equivalent amounts. From the mixture, glucose crystallizes more easily than fructose, and can be obtained pure without much difficulty.

Commercially, glucose is manufactured in large quantities from starch. Commercial glucose usually contains considerable amounts of maltose, dextrin, and other substances.

Glucose crystallizes from water in microscopic, six-sided tablets which contain one molecule of water. It crystallizes from absolute alcohol in needles which are free from water. It is optically active. $[\alpha]_D = +52.7°$ for a ten per cent aqueous solution. The value increases slightly with increasing concentration of the solution. A cold, freshly prepared solution gives a rotation which is much higher; but after standing for some time, or after boiling for a few minutes, the rotation falls to the normal value. This phenomenon is called "birotation" or "mutarotation," and, if not taken into account, is liable to cause serious error in working with some of the sugars.

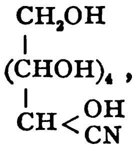
Pure glucose is only about one-half as sweet as cane sugar. Commercial glucose is still less sweet.

Structure of Glucose. — The view held of the structure of glucose depends on the following facts:

1. It gives by reduction with sodium amalgam *d*-sorbite, $C_6H_{14}O_6$, and this, by reduction with hydriodic acid, gives secondary hexyl iodide, $CH_3CHICH_2CH_2CH_2CH_3$, proving the presence of a normal chain of carbon atoms.

2. It gives, when heated with acetic anhydride and zinc chloride, a pentacetate, $C_6H_7O_6(C_2H_3O)_5$, demonstrating the presence of five hydroxyl groups.

3. It combines with hydrocyanic acid to form a cyanhydrin,



$$\begin{array}{l} CH_2OH \\ | \\ (CHOH)_4 \, , \\ | \\ CH<\begin{smallmatrix} OH \\ CN \end{smallmatrix} \end{array}$$

which can be saponified to α-glucoheptonic acid, $CH_2OH(CHOH)_5CO_2H$. The lactone-anhydride of this acid is reduced to normal heptylic acid, $CH_3(CH_2)_5CO_2H$, by heating with hydriodic acid. This proves that the hydrocyanic acid must have combined with the end carbon atom, and that glucose contains an aldehyde and not a ketone group.

4. Anhydrous glucose exists in two forms called α and β glucose, for which the specific rotations are +109° and +20° and the molecular rotations 19600 and 3600. If we assume that in the α-glucose the end carbon atom gives a right-handed rotation and in the β-glucose a left-handed one, the effect of the rest of the molecule remaining unchanged, the difference between the two molecular rotations should be twice the rotation due to the end carbon atom. This supposition receives a very strong support from the fact that three other sugars which have α and β forms have almost the same difference between the molecular rotations of the two forms as that found for α and β glucose. These

facts also point strongly to the lactone formula given on p. 360 for anhydrous glucose. (See Hudson, J. Am. Chem. Soc., **31**, 66.) The hydrate probably has the formula

$$CH_2OHCHOHCHOHCHOHCHOHCH(OH)_2.$$

Synthesis of Glucose. — *d*-Glucose has been prepared, synthetically, by the following series of reactions. Glycerol, by oxidation with bromine and sodium carbonate, gives glycerol-aldehyde, $CH_2OH,CHOH,CHO$. When this is allowed to stand for four or five days in an aqueous solution containing one per cent of sodium hydroxide, it polymerizes to a sugar which was called at first α-acrose, but which has been shown to be *dl*-fructose,

$$CH_2OH,CHOH,CHOH,CHOHCOCH_2OH.$$

This is reduced by sodium amalgam to *dl*-mannite,

$$CH_2OH(CHOH)_4CH_2OH,$$

and this, in turn, can be oxidized to *dl*-mannose,

$$CH_2OH(CHOH)_4CHO;$$

and *i*-mannonic acid,

$$CH_2OH\ (CHOH)_4CO_2H.$$

The *i*-mannonic acid can be separated into its active components by means of the strychnine salt. The *d*-mannonic acid, when heated with pyridine, is partly converted into *d*-gluconic acid, which has the same structural arrangement but a different configuration. Finally *d*-gluconic acid gives *d*-glucose by reduction.

A hot solution of glucose reduces a hot Fehling's solution,* and this reaction can be used both for its detection and

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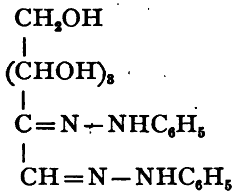
* Fehling's solution, which is much used in work with sugars, is best kept in the form of two separate solutions, the first containing, in 500 cc., 173 grams of Rochelle salt and 50 grams of sodium hydroxide; the second containing, in 500 cc., 34.639 grams of crystallized copper sulphate. For use, equal volumes of the two solutions are mixed.

quantitative determination, when other reducing substances are absent.

Glucosazone. — When a solution containing glucose is warmed with phenyl hydrazine acetate, *glucosazone*,



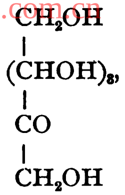
$$\begin{array}{l} CH_2OH \\ | \\ (CHOH)_3 \\ | \\ C=N-NHC_6H_5 \\ | \\ CH=N-NHC_6H_5 \end{array}$$

is formed. The phenyl hydrazine combines at first with the glucose to form a phenyl hydrazone, a second portion of the hydrazine then oxidizes the adjacent $\overset{|}{\underset{|}{\mathrm{C}}}\mathrm{HOH}$ group, and finally, more of the phenyl hydrazine reacts with the ketone group which is produced. Many other sugars react in a similar manner to form *osazones*, and the resulting compounds have been extremely useful for the separation and identification of different sugars. Glucosazone crystallizes in yellow needles, which melt, when quickly heated, at 206°.

d-Glucose ferments easily under the influence of brewer's yeast, giving chiefly alcohol and carbon dioxide (p. 130). *l*-Glucose, on the contrary, does not ferment with brewer's yeast, and one-half of *dl*-glucose, only, is fermented by the same agency. E. Fischer has suggested that some relation similar to that of a key to its lock must exist, in such cases, between the compounds of the organism and the fermentable body.

l-Glucose was prepared by the reduction of *l-gluconic anhydride* (see above), and *dl*-glucose by the reduction of *dl*-gluconic anhydride. Neither has been found in nature.

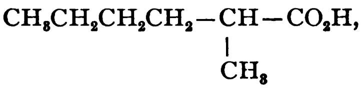
l-Fructose (levulose, fruit sugar, *d*'-fructose),



$$\begin{array}{l} CH_2OH \\ | \\ (CHOH)_3, \\ | \\ CO \\ | \\ CH_2OH \end{array}$$

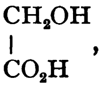
is found accompanying *d*-glucose in most sweet fruits, and is very widely distributed in nature. It is formed in equal amount with *d*-glucose by the hydrolysis of cane-sugar, the mixture of the two being called "invert sugar."

Fructose forms a pentacetyl derivative. It is reduced to a mixture of mannite and sorbite by sodium amalgam. It combines with hydrocyanic acid to form a cyanhydrin. The acid obtained by saponifying the cyanhydrin is reduced to *methyl butyl acetic acid*,



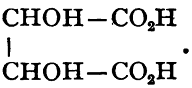
$$\begin{array}{l} CH_3CH_2CH_2CH_2-\overset{}{CH}-CO_2H, \\ \qquad\qquad\qquad\qquad\quad | \\ \qquad\qquad\qquad\qquad\quad CH_3 \end{array}$$

on heating with hydriodic acid. Fructose gives with phenyl hydrazine, an osazone identical with that obtained from glucose. By oxidation with nitric acid it gives glycollic acid,



$$\begin{array}{l} CH_2OH \\ | \qquad , \\ CO_2H \end{array}$$

and inactive tartaric acid,

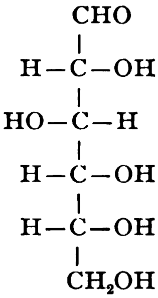


$$\begin{array}{l} CHOH-CO_2H \\ | \qquad\qquad . \\ CHOH-CO_2H \end{array}$$

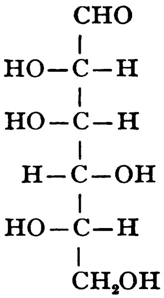
These facts establish its structure.

l-Fructose reduces Fehling's solution, and may be determined quantitatively in that manner. *l*-Fructose undergoes fermentation with brewer's yeast; *d*-fructose ferments still more easily, so that it is possible, by partial fermentation, to obtain the *l*-fructose from the *dl*-fructose (α-acrose) prepared by synthesis.

A considerable number of other sugars of the same structure as glucose, and a few of the same structure as fructose, but differing from them in configuration and properties, are known. These are distinguished by formulae, of which the following are illustrations:



d-Glucose.



d-Gulose.

By placing the hydroxyl group to the right or left of a given carbon atom, it is intended to indicate whether that carbon atom produces a right-handed or left-handed rotation. A study of the possible combinations shows that there may be sixteen different configurations for a substance of the structure of glucose. Eleven such substances are now known, and five racemic forms resulting from the combination of forms which are optically opposite. By means of a careful study of the relations between the different forms, of their relations to mannite and sorbite, to saccharic and mucic acids, and to active tartaric acid, Emil Fischer has determined the configuration of glucose and of several other aldohexoses with a good degree of certainty. This must be considered as the most difficult problem thus far solved in the study of space-isomerism.

Inosite (**hexoxyhexahydrobenzene, or hexahydroxycyclohexane**), $C_6H_6(OH)_6+2H_2O$, is found in the lungs, kidneys, liver, and brains of oxen, sometimes in the urine, and in a variety of fruits and vegetables. It does not reduce Fehling's solution. Nitric acid oxidizes inosite to tetroxyquinone, $C_6H_4O_6$; hydriodic acid, at 170°, reduces it to phenol, triiodophenol, and a trace of benzene.

Although isomeric with the other hexoses, inosite is radically different from them in structure and properties.

Sugars containing seven, eight, and nine carbon atoms in a molecule have been prepared synthetically, but none of them have been found in natural products.

DISACCHARIDES, $C_{12}H_{22}O_{11}$.

Saccharose (**cane-sugar**), $C_{12}H_{22}O_{11}$, is very much the most important of all the sugars. It is prepared commercially from sugar-cane, beets, sorghum, and the sap of maple-trees, and is found in a very great variety of plants and vegetables.

In the manufacture of sugar from the sugar-beet, the material is first cut into very small, thin pieces. These are then subjected to the action of water in a "diffusion battery" of ten or twelve large iron cylinders, so arranged that the water may enter at any one of the cells desired, and circulate in order through the others. In contact with water, the amount of sugar in the beet-chips, and in the water surrounding them, is quickly equalized by diffusion. By so arranging the current of water that it enters the battery at the cell where the chips are most nearly exhausted, and leaves at the cell which has been last filled, it is possible, both to secure a very complete removal of the sugar, and also to obtain a solution with a content of sugar approaching very nearly to that of the original beet-juice.

The sugar-cane is sometimes treated by the diffusion process, but more usually the sap is expressed from the cane by means of heavy iron or steel rollers. A very much smaller per cent of sugar (about 70 per cent) is recovered by the rolls than by diffusion (about 84 per cent); but the residue can be used as fuel in the former case, and this is usually an important item in the localities where sugar-cane is chiefly grown. The exhausted beet-chips, on the other hand, are often used as a cattle food.

The juice or solution is next treated with milk of lime or powdered lime, and warmed to precipitate phosphoric acid, oxalic acid, citric acid, albuminous bodies, and other impurities. The clear solution, after their removal, is treated with carbon dioxide, and sometimes with sulphur dioxide, to remove the excess of lime. As even a trace of acid causes some "inversion" and loss of sugar, it is important that the solution shall always remain faintly alkaline.

The solution is then evaporated in vacuum pans, the syrup cooled and allowed to crystallize, and the "molasses" separated from the crystals by means of centrifugals. The crude sugar is usually further purified in sugar refineries by solution, filtering through boneblack, and recrystallizing.

The "molasses," especially that from cane-sugar, is often sold as such; that from beet-sugar is usually fermented for the manufacture of alcohol; and the spent liquors, after distillation, are evaporated and calcined, partly for the manufacture of methyl alcohol and other products, partly for the recovery of potassium salts and other inorganic compounds of value as fertilizers.

Pure cane sugar, whether from the sugar-cane or beets, is without effect on Fehling's solution. It is optically active, $[\alpha]_D = +66.514°$ at 20° for a solution containing 26.004 grams of sugar in a volume of 100 cc., the value varying slightly with the temperature and concentration (Wiley, J. *Am. Ch. Soc.* **21**, 594). When heated for a short time with dilute hydrochloric acid, it is hydrolyzed, giving a mixture of *d*-glucose and *l*-fructose, which is known as "invert" sugar, since the fructose causes a greater rotation to the left than glucose does to the right. Since most impure commercial sugars contain a mixture of cane sugar and invert sugar, a determination of the rotatory power before and after inversion furnishes the necessary data for calculating the per cent of each which is present. Such determinations are made the basis for the collection of duty to the amount of millions of dollars annually at our ports of entry.

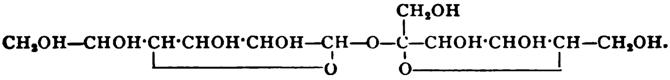
Cane sugar does not ferment directly, but it is easily inverted by an enzyme which always accompanies ordinary yeast, and both the glucose and fructose then undergo fermentation.

Cane sugar crystallizes in monoclinic prisms. It melts at 160°. At temperatures below 20° it is soluble in one-half its weight of water. At 50° it dissolves in a little less than one-fourth of its weight of water.

Cane sugar, as well as other sugars, forms, with bases, compounds called saccharates, of which those with calcium, strontium and barium are most important. Those of the cane sugar with calcium are $C_{12}H_{22}O_{11} \cdot CaO + 2H_2O$, $C_{12}H_{22}O_{11} \cdot 2CaO$, and $C_{12}H_{22}O_{11} \cdot 3CaO$. The first is easily soluble, the second dissolves in 33 parts of cold water, the third in 200 parts of cold water.

Cane sugar also forms double compounds with sodium chloride and with other salts, as, for example, $C_{12}H_{22}O_{11} . NaCl$.

The exact structure of cane sugar has not been fully established. It forms no compound with phenyl hydrazine, and hence probably contains no aldehyde or ketone group, a fact which also explains its failure to react with Fehling's solution. It forms an octacetate, $C_{12}H_{14}O_{11}(C_2H_3O)_8$, indicating the presence of eight hydroxyl groups. The ease with which it is hydrolyzed by acids indicates that the radicals of glucose and fructose, which it must contain, are united by oxygen. The following formula agrees with these facts, and is the most probable of those which have been proposed:



$$\mathrm{CH_2OH{-}CHOH{\cdot}\underbrace{CH{\cdot}CHOH{\cdot}CHOH{-}CH}_{O}{-}O{-}\underbrace{\overset{CH_2OH}{C}{-}CHOH{\cdot}CHOH{\cdot}CH}_{O}{-}CH_2OH.}$$

Lactose (milk sugar), $C_{12}H_{22}O_{11}+H_2O$, is found in milk, and is prepared from the whey which remains after separating the caseïn in making cheese. It is much less easily soluble in water than cane sugar, a saturated solution at 10° containing only 14.55 per cent of lactose.

$[\alpha]_D=52.5°$. The anhydrous milk-sugar, when first dissolved, gives a smaller rotation, gradually increasing to the normal value. The crystallized sugar, on the other hand, gives a larger rotation at first. Either solution gives the normal value after warming. (See p. 362.)

Lactose reduces Fehling's solution and may be determined in that way, but the amount of cuprous oxide precipitated is less than that from the same weight of glucose or fructose. Lactose is hydrolyzed by dilute acids to glucose and galactose. It is neither hydrolyzed nor fermented by ordinary yeast, but may be fermented by *schizomycetes*, giving alcohol and lactic acid.

Maltose, $C_{12}H_{22}O_{11}+H_2O$, is formed, together with dextrin, by the action of the diastase of malt upon starch (p. 130). It is easily soluble in water. $[\alpha]_D=+137.04°$ for the anhydrous maltose. The rotation of a freshly prepared solution is less. Maltose reduces Fehling's solution, the ratio of maltose to cuprous oxide formed being greater than for lactose. Maltose gives only glucose by hydrolysis with acids. The hydrolysis takes place with much greater difficulty than in the case of cane sugar. Maltose ferments directly with brewer's yeast, giving chiefly alcohol. Both lactose and maltose give compounds with phenyl hydrazine, indicating the presence of an aldehyde group.

TRISACCHARIDES, $C_{18}H_{32}O_{16}$.

Raffinose (melitose, melitriose), $C_{18}H_{32}O_{16}+5H_2O$, is found in the molasses from the preparation of beet sugar, in cottonseed, and in several other substances of vegetable origin. It is dextro-rotatory, $[\alpha]_D=104.5°$. It does not reduce Fehling's solution. It is hydrolyzed by acids at first to glucose and melibiose; and the latter gives, by further hydrolysis, glucose and galactose. It is partially fermented by yeast. Raffinose occasionally crystallizes with cane sugar in peculiar, pointed crystals. These will, of course, give a higher rotation than pure cane sugar.

If the natural carbohydrates are arranged in the order of complexity, cellulose and starch would stand at one end, as having the highest molecular weights, while glucose and xylose would stand at the other.

Cellulose, $(C_6H_{10}O_5)_x$, forms the chief constituent of the woody fiber of plants. If cotton-wool is treated with ether, alcohol, sodium hydroxide, dilute hydrochloric acid, and hydrofluoric acid, and thoroughly washed, the residue is nearly pure cellulose. The best grades of washed filter-papers are practically pure cellulose.

Cellulose is insoluble in all of the ordinary solvents. If, however, a solution containing copper sulphate and ammonium chloride is precipitated with sodium hydroxide, the precipitate thoroughly washed, and then dissolved in ammonia, a solution is obtained, called "Schweitzer's reagent," in which cellulose is soluble. The cellulose is reprecipitated by acids or salts.

If cellulose is dissolved in concentrated sulphuric acid, and the solution is diluted and boiled, it is partly converted into dextrin and glucose.

Paper consists mainly of cellulose. The best grades are manufactured from flax or from linen rags, cheaper kinds from cotton rags, wood, straw, and vegetable fibers of other sorts. Whatever material is used is at first disintegrated by boiling with sodium hydroxide or lime, and by mechanical means, to secure a uniform pulp. Bleaching agents are also often used. The pulp is then evenly distributed on a wire screen, passed through rolls, and dried.

When unsized paper is dipped in strong sulphuric acid for a moment, and then washed with water and ammonia, it is superficially changed, and is converted into tough *parchment paper*, which may be used as a substitute for real parchment and for other purposes.

Gun-cotton, Nitrocellulose, Pyroxylin.—When cotton wool is treated with a mixture of concentrated sulphuric and nitric acids, it is converted into esters of nitric acid which have been erroneously called *nitrocellulose.** A more correct name is cellulose nitrate. According to the strength of the acid, the character of the fiber, and the length of treatment, these may vary from the *dinitrate*, $C_{12}H_{18}(NO_3)_2O_8$, to the *hexanitrate*, $C_{12}H_{14}(NO_3)_6O_4$. The lower forms are soluble in

* For the nature of true nitro compounds see p. 411.

ether, amyl acetate, camphor, and other solvents. The solution in ether and alcohol is called collodion solution. The solution in amyl acetate is much used for lacquers, and the solution in camphor is celluloid.

The higher nitrated cotton is the explosive known as gun-cotton. The pure hexanitrate is the basis of one of the best of the smokeless powders, *indurite* (Munroe, *J. Am. Chem. Soc.*, 18, 833).

Starch (amylum), $(C_6H_{10}O_5)_x$, is very widely disseminated in the vegetable kingdom, and forms a large percentage of the weight of corn, wheat, rye, barley, oats, rice, and potatoes. In its natural condition, starch is found in an organized form as starch granules, which differ from each other so markedly that the source from which a given sample of starch is derived can usually be determined by a microscopic examination.

In manufacturing starch from corn, the grain is at first softened with water, then ground, and the wet material is allowed to ferment, which softens the gluten, and renders the washing away of the starch granules easier. After a time the material is agitated in a current of water, which carries off the starch in a sort of emulsion. From this it is allowed to settle, the water is removed as far as possible by centrifugals, and the residue dried, at first at a low temperature to prevent coagulation. The finished starch retains from 12 to 18 per cent of water.

Ordinary starch is insoluble in water. If boiled with water, the cell walls are ruptured, and the starch gelatinizes. With a considerable quantity of water, an emulsion is obtained which passes readily through filter paper, but it is doubtful if this is a true solution. Starch gives a blue color with an iodine solution containing potassium iodide or hydriodic acid. Starch is converted by diastase into maltose and dextrin, the proportion between the two varying somewhat with the conditions of treatment. Since maltose contains twelve atoms of carbon in the molecule, and some forms of dextrin at least thirty-six atoms of carbon, it is supposed that the molecule of starch is very complex.

Starch is converted into dextrin, by heat. It is converted successively into dextrin, maltose, and glucose by heating with dilute acids. (For rate of conversion see Rolfe and Defren, *J. Am. Chem. Soc.* 18, 869.)

Dextrin is intermediate between starch and maltose or glucose. Commercial dextrin is prepared by heating starch for some time at 200°–210°, or by moistening it with nitric acid and heating at a lower temperature. Other forms of dextrin can be prepared by the action of dilute acids or of diastase on starch. Several different kinds of dextrin have been isolated. The forms most certainly characterized have the formula, $C_{36}H_{62}O_{31}$. All forms are easily soluble in water, but are insoluble in strong alcohol.

All forms of dextrin are strongly dextro-rotatory, the rotation for the ordinary forms being about $[\alpha]_D = +196°$. The various forms vary from $[\alpha]_D = 182°$, to $[\alpha]_D = 196°$.

Dextrin gives with iodine a violet or red color. It is converted into glucose by boiling with dilute acids. It is used as a gum, especially for the backs of postage stamps, gummed labels, etc.

Dextrin does not ferment with yeast.

Glycogen is a body somewhat resembling dextrin. It is found in the liver of men and of herbivorous animals. Dilute acids convert it into glucose.

Inulin is a substance found in the roots of dahlias and other plants. It is soluble in hot water, insoluble in alcohol.

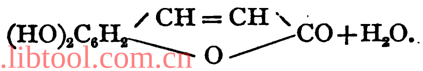
It is laevo-rotatory, $[\alpha]_D = -36.57°$, and is converted into *l*-fructose by boiling with dilute acids, and also by the enzyme inulase.

Arabin, $C_{10}H_{18}O_9$(?), is the chief constituent of *gum arabic.* It resembles dextrin in its general properties, but is converted to arabinose, $C_5H_{10}O_5$, by boiling with dilute acids.

Xylan is a gumlike material found in straw, and probably in corncobs, wheat bran, and many other vegetable materials. It is converted to xylose, $C_5H_{10}O_5$ by boiling with dilute acids. As xylan, and perhaps other bodies called *pentosans,* form a considerable portion of straw, hay, and other food materials used for cattle and horses, the question of their food value is one of some importance, but one which has not yet been satisfactorily answered. The determination of these constituents is effected by boiling the materials with dilute acids which first hydrolyze them to xylose, which is then further converted into *furfural* (p. 360).

Glucosides. — There are found in nature a considerable number of vegetable substances which yield, by hydrolysis, a sugar and some other characteristic compound or compounds. Such bodies are called glucosides. The hydrolysis may usually be effected by means of dilute acids, but is also often caused by some special enzyme, or ferment, which accompanies the glucoside. The sugar formed is usually glucose, but rhamnose, mannite, phloroglucinol, and other compounds are occasionally produced. More than a hundred glucosides have been studied with some care, and, doubtless, very many more exist. Only a few of the most interesting can be mentioned.

Aesculin, $C_{15}H_{16}O_9 + 1\frac{1}{2}H_2O$, is found in horse-chestnuts. It gives, with dilute acids, or with the enzyme, *emulsin,* glucose and *aesculetin,*



Amygdalin, $C_{20}H_{27}NO_{11} + 3H_2O$, is found in bitter almonds, in peach stones, and in the seeds of apples and pears, etc., it is hydrolyzed by dilute acids, or *emulsin*, to glucose, benzaldehyde, and hydrocyanic acid (p. 182).

Coniferin, $C_{16}H_{22}O_8 + 2H_2O$, is found in the cambium of the conifers and in asparagus. It gives, with dilute acids, glucose and a resin; with emulsin it is slowly hydrolyzed to glucose and *coniferyl alcohol,* $CH_3O.C_6H_3(OH).C_3H_4OH$. By oxidation with chromic acid it gives vanillin (p. 186).

Digitaleïn, $C_{22}H_{38}O_9$, is found in the leaves of *Digitalis purpurea.* It is decomposed by dilute acids into glucose and *digitaliretin,* $C_{16}H_{26}O_3$.

Tannins are acid glucosides, found in oak-bark, sumac, tea-leaves, canaigre root, and many other plants. Most of them yield a sugar, which is not always glucose, and other substances, on boiling with dilute acids. Their great commercial value depends on the fact that they unite with substances found in the skins of animals forming non-putrefactive compounds. They all give green or blue color reactions with ferric chloride. The value of tanning materials is determined by preparing an aqueous extract, and treating this with some hide powder, which combines with the tannin. The difference between the total solid matter contained in the original extract and that contained in the extract after treatment with the hide powder furnishes the data necessary for the determination.

Indican, $C_{26}H_{31}NO_{17}$, is found in the *Indigofera tinctoria* of the East Indies and in various other plants. In the manufacture of *indigo* it is hydrolyzed by a ferment which forms when the plant is covered with water and exposed to the air. It is also hydrolyzed by boiling with dilute acids, giving indiglucin and indigo blue.

$$2C_{26}H_{31}NO_{17} + 4H_2O = \underset{\text{Indiglucin.}}{6C_6H_{10}O_6} + \underset{\text{Indigo blue.}}{C_{16}H_{10}N_2O_2}.$$

The value of the indigo prepared in this manner from vegetable sources during the year 1900 was about $15,000,000.

Iridin, $C_{24}H_{26}O_{13}$, is found in violet root. It gives, when heated with dilute sulphuric acid and alcohol, glucose and *irigenin,* $C_{18}H_{16}O_8$. The body which gives to violet root its pleasant odor is not iridin but *irone* (p. 197).

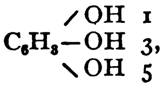
Myronic Acid, $C_{10}H_{17}NS_2O_9$, is found in the seed of the black mustard in the form of its potassium salt,

$$C_{10}H_{16}NS_2O_9K + H_2O,$$

called *sinigrin.* Under the fermentative action of myrosin, an enzyme found in white mustard, sinigrin yields glucose, acid potassium sulphate, and *allyl isothiocyanate* or *allyl mustard oil.*

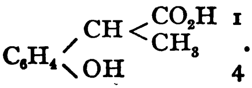
$$C_{10}H_{16}NS_2O_9K + H_2O = C_6H_{12}O_6 + C_3H_5NCS + KHSO_4.$$

Phlorizin, $C_{21}H_{24}O_{10} + 2H_2O$, is found in the bark of the roots of apple, cherry, and plum trees. It is hydrolyzed by acids to glucose and *phloretin,* $C_{15}H_{14}O_5$. Phloretin, in turn, yields, on boiling with a solution of potassium hydroxide, *phloroglucinol,*



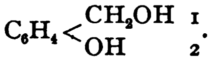
$$C_6H_3\begin{cases}-OH & 1\\ -OH & 3,\\ -OH & 5\end{cases}$$

and *phloretic acid,*



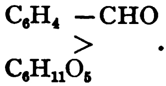
$$C_6H_4\begin{cases}-CH<\begin{matrix}CO_2H\\ CH_3\end{matrix} & 1\\ -OH & 4\end{cases}.$$

Salicin, $C_{13}H_{18}O_7$, is found in willow bark and leaves, and in several other plants. It is hydrolyzed by emulsin, or by ptyaline, an enzyme formed in the saliva, to glucose and *saligenin* or *o-hydroxybenzyl alcohol*,



$$C_6H_4 < \begin{matrix} CH_2OH & 1 \\ OH & 2 \end{matrix} .$$

Salicin is intensely bitter. It is used in medicine. It is oxidized by nitric acid to *helicin*,



$$\begin{matrix} C_6H_4 & -CHO \\ & > \\ C_6H_{11}O_5 & \end{matrix} .$$

Saponin, $C_{32}H_{52}O_{17}$, is found in soap root (*saponaria officinalis*). It gives, with dilute acids, sugar and *sapogenin*, $C_{14}H_{22}O_2$. Saponin gives, with water, a suds very much like that produced by soap. The soap-root is used in some places instead of soap.

Solanine, $C_{52}H_{93}NO_{18}$, is a basic glucoside, found in deadly nightshade (*solanum nigrum*) and in potato-balls. It gives, with acids, *solanidine*, $C_{40}H_{61}NO_2$, and sugar. Solanine is a poison.

BITTER PRINCIPLES.

Mention may be made here of the so-called "bitter principles," natural compounds, mostly of vegetable origin, which contain only carbon, hydrogen, and oxygen. To this class belong absinthin, aloïn, anemonin, cantharidin, capsaïcin, cascarin, picrotoxin, and more than one hundred other substances. Some of these have medicinal value, others are poisons. In a few cases they have been studied in careful detail, and the structure has been established, but about the majority of them very little is known.

Laboratory Exercises.

1. Determination of the specific rotation of various sugars.
2. Determination of cane sugar and invert sugar in molasses.
3. Determination of starch in some grain, as corn or wheat.
4. Preparation of glucosazone.
5. Test of urine for glucose.

CHAPTER XVIII.

HALOGEN COMPOUNDS.

VERY few, if any, halogen organic compounds are found in nature. Such compounds are, however, of very considerable importance, and it has been necessary to refer to many of them in the preceding pages. Some methods of preparing them, and some of their properties, have also been incidentally mentioned.

Those substances which contain chlorine, bromine, and iodine are of most importance, compounds of fluorine* being comparatively rare and unimportant.

METHODS OF PREPARATION.

1. Direct substitution of a halogen atom for hydrogen. As chlorine and bromine are very active agents, it is possible to obtain many halogen compounds by the direct action of these elements upon hydrocarbons and their derivatives. Thus chlorine may give the following series of reactions with methane:

$$CH_4 + Cl_2 = \underset{\text{Methyl chloride.}}{CH_3Cl} + HCl.$$

$$CH_3Cl + Cl_2 = \underset{\text{Methylene chloride.}}{CH_2Cl_2} + HCl.$$

---

* V. Meyer and Jacobson do not, apparently, include fluorine among the halogens. There seems to be no logical reason for excluding it, however, and it will be so included here.

$$CH_2Cl_2 + Cl_2 = \underset{\text{Chloroform.}}{CHCl_3} + HCl.$$

$$CHCl_3 + Cl_2 = \underset{\substack{\text{Carbon}\\\text{tetrachloride.}}}{CCl_4} + HCl.$$

The products are also named, logically, *monochlormethane*, *dichlormethane*, *trichlormethane*, *tetrachlormethane*.

While this series of reactions is of great theoretical interest, and similar reactions are of considerable importance for the identification of hydrocarbons of the marsh-gas series, it is practically impossible, in that series, to limit the reaction to the formation of a single compound; and the isolation of the different substances formed is attended with considerable difficulty.

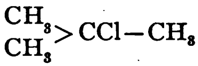
The halogen derivatives of the hydrocarbons are distinguished as *primary*, *secondary*, and *tertiary* in the same sense as the alcohols (p. 136); thus:

$$CH_3CH_2CH_2CH_2Cl$$

is primary butyl chloride.

$$CH_3CH_2CHClCH_3$$

is secondary butyl chloride.



$$\begin{matrix}CH_3\\CH_3\end{matrix}\!\!>CCl-CH_3$$

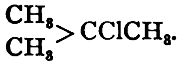
is tertiary isobutyl chloride.

The official names, 1-chlorbutane, 2-chlorbutane, and 2-chlor-2-methyl propane, are also used, and are to be preferred.

When chlorine acts upon the normal homologues of methane, both primary and secondary chlorides are formed. Pentane gives

$$CH_3CH_2CH_2CH_2CH_2Cl \text{ and } CH_3CH_2CH_2CHClCH_3.$$

Hydrocarbons containing a tertiary hydrogen atom give the tertiary chloride. Isobutane gives

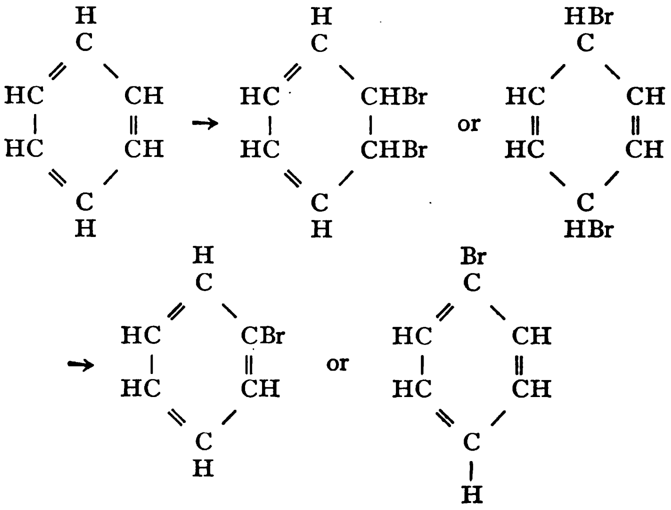


$$\begin{matrix}CH_3\\CH_3\end{matrix}\!>CClCH_3.$$

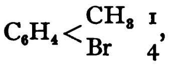
A second atom of chlorine combines with the same carbon atom as the first. Ethyl chloride gives *ethylidene chloride*, CH_3CHCl_2, not *ethylene chloride*, CH_2ClCH_2Cl.

Bromine does not act upon hydrocarbons of the marsh-gas series at ordinary temperatures. By heating in sealed tubes substitution products can be obtained.

Halogen substitution products can be obtained from unsaturated hydrocarbons and their derivatives by the direct action of the elements only when the addition, which occurs at first, is followed by a loss of hydrochloric or hydrobromic acid. In the aromatic series, even, where the action usually has every appearance of being a direct substitution, it is probable that addition takes place at first:

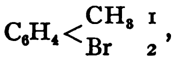


Chlorine and bromine enter the nucleus when they act upon homologues of benzene in the cold, but they enter the side chain when they act upon the boiling hydrocarbon. Thus toluene and p-xylene give with bromine in the cold (best with the addition of a little iron to form ferric bromide, which greatly aids the action), *p-bromtoluene*,



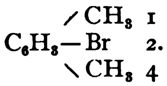
$$C_6H_4<\begin{matrix}CH_3 & 1\\ Br & 4\end{matrix},$$

o-bromtoluene,



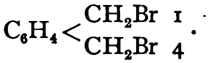
$$C_6H_4<\begin{matrix}CH_3 & 1\\ Br & 2\end{matrix},$$

and *brom-p-xylene*,



$$C_6H_3\begin{matrix}/CH_3 & 1\\ -Br & 2.\\ \backslash CH_3 & 4\end{matrix}$$

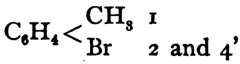
The boiling hydrocarbons give, on the other hand, *benzyl bromide*, $C_6H_5CH_2Br$, and *p-xylylene bromide*,



$$C_6H_4<\begin{matrix}CH_2Br & 1\\ CH_2Br & 4\end{matrix}.$$

The latter action takes place best in direct sunlight.

Laws of Positions Taken by Substituting Groups. — Of still greater interest are the laws which govern the position which the halogen atom takes in the benzene nucleus with regard to other substituting groups. It is found that in the formation of substitution products of benzene and its derivatives, whether the substituting group is chlorine, bromine, the nitro group (NO_2), or the sulphonic acid group (SO_2OH), the ortho and para positions are intimately associated while the meta position stands by itself. Thus by the direct bromination of toluene, $C_6H_5CH_3$, a mixture of the ortho and para bromtoluenes,

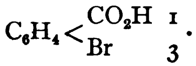


$$C_6H_4<\begin{matrix}CH_3 & 1\\ Br & 2 \text{ and } 4,\end{matrix}$$

is formed, while benzoic acid,

$$C_6H_5CO_2H,$$

gives, almost exclusively, metabrombenzoic acid,

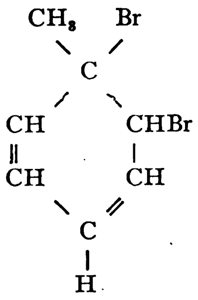


$$C_6H_4<\begin{matrix}CO_2H & 1\\ Br & 3\end{matrix}.$$

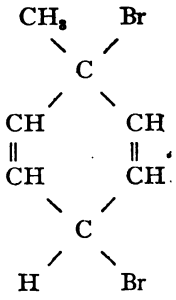
A careful study of the matter has shown that the substituting atom or group enters chiefly in the para or ortho position with reference to CH_3, C_2H_5, OH, NH_2, Cl, Br, or I, but mainly in the meta position toward CO_2H, SO_3H, CCl_3, NO_2, CHO, or CN.

In general, it may be stated that positive groups cause a substituent to enter in the ortho or para position, while negative groups throw it to the meta position; but, curiously enough, hydroxyl, chlorine, bromine, and iodine are associated, in their effect, with the positive groups.

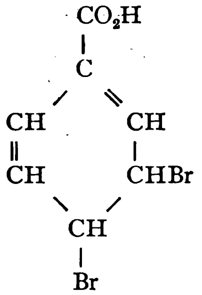
No explanation for these laws of substitution has been generally accepted. They are, perhaps, due to the formation of addition products; thus toluene may give, at first, the compounds:



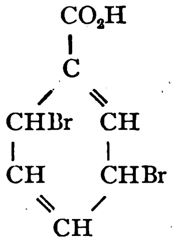
and



The former would give, by loss of hydrobromic acid, orthobromtoluene, while the latter would give parabromtoluene. It may be that benzoic acid gives the addition compounds:

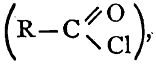


and

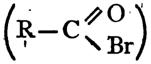


Either of these may give the metabrombenzoic acid by loss of hydrobromic acid.

Halogen Substitution Products of Acids.—In preparing halogen substitution products of the aliphatic acids it has been found that the chlorides



$\left(R-C\begin{smallmatrix}{\nearrow O}\\{\searrow Cl}\end{smallmatrix}\right)$, or bromides



$\left(R-C\begin{smallmatrix}{\nearrow O}\\{\searrow Br}\end{smallmatrix}\right)$

of the acids react much more easily than the free acids. In practical work the acid is either first treated with phosphorus pentachloride and the mixture of acid chloride and phosphorus oxychloride then acted upon with bromine; or the acid is mixed with red phosphorus and the bromine added slowly:

$$CH_3CH_2CO_2H + PCl_5 = CH_3CH_2COCl + POCl_3 + HCl$$

$$CH_3CH_2COCl + Br_2 = CH_3CHBrCOCl + HBr.$$

Or $$3CH_3CH_2CO_2H + P + 11Br = 3CH_3CHBrCOBr + HPO_3 + 5HBr.$$

The chloride or bromide of the acid can be decomposed by treatment with water or with glacial formic acid:

$$CH_3CHBrCOCl + HCO_2H = CH_3CHBrCO_2H + CO + HCl.$$

α-Brompropionic acid.

It has been found that only those aliphatic or alicyclic acids which contain hydrogen in the α-position with reference to the carboxyl (i.e. those containing the group,

$$R-CH_2-CO_2H,$$

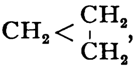
or

$$\begin{matrix} R \\ R \end{matrix}\!\!>CHCO_2H,$$

can be brominated in this manner, and that the bromine always enters in the α-position. Since the bromine of the brom acids obtained may be replaced by hydroxyl, or may be eliminated with a neighboring hydrogen atom, giving an α-β-unsaturated acid, the preparation of such α-brom-acids has often proved of great practical importance.

Many other organic compounds may give halogen derivatives by direct substitution, but a further discussion of this method of preparation seems to be unnecessary.

2. By direct addition to unsaturated or cyclic compounds. In general chlorine and bromine add themselves to unsaturated compounds in such amount as to give a halogen derivative of the corresponding saturated aliphatic or alicyclic compound. Iodine also adds itself to such compounds, but less easily, and the resulting iodine derivatives are unstable.

Derivatives of cyclopropane also take up bromine directly. Thus cyclopropane,  $CH_2<\begin{matrix} CH_2 \\ | \\ CH_2 \end{matrix}$, gives trimethylene bromide (1, 3-dibrompropane), $CH_2BrCH_2CH_2Br$.

Benzene adds six chlorine or six bromine atoms directly, in the sunlight; but the resulting compounds are decomposed by heat, giving 1, 2, 4 trichlor- or tribrombenzene and hydrochloric or hydrobromic acid.

3. By the addition of hydrochloric, hydrobromic, or hydriodic acid to unsaturated compounds. In accordance with the "positive negative" law (p. 191) the halogen atom adds itself to the carbon atom bearing least hydrogen, or to the carbon atom farthest removed from a carboxyl group:

$CH_3CH{=}CH_2$ gives CH_3CHICH_3,
Propylene. Isopropyl iodide.

$CH_2{=}CHCO_2H$ gives $CH_2BrCH_2CO_2H$.
β-brompropionic acid.

When γ-brom-acids are formed in this manner they are usually unstable, and pass very readily into lactones (p. 318).

4. By the replacement of hydroxyl by chlorine, bromine, or iodine. Alcohols and hydroxyl derivatives are very common among natural organic substances; and, since they are much more reactive than the hydrocarbons, they are especially suitable for the preparation of halogen compounds. In some cases the alcohols will react directly with the halogen acids, as,

$$CH_3OH + HI = CH_3I + H_2O.$$
Methyl iodide.

More usually a chloride, bromide, or iodide of phosphorus is allowed to act upon the alcohol or hydroxyl compound. The compound of phosphorus may be prepared before addition to the alcohol, or, in the case of stable compounds, the alcohol may be mixed with red phosphorus and the bromine or iodine added slowly:

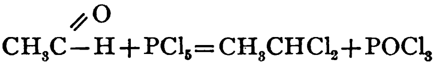
$$3CH_3CH_2OH + P + 3Br = 3CH_3CH_2Br + H_3PO_3,$$

$$5CH_3OH + P + 5I = 5CH_3I + H_3PO_4 + H_2O,$$

$$\underset{\text{Phenol.}}{C_6H_5OH} + PCl_5 = \underset{\text{Monochlorbenzene.}}{C_6H_5Cl} + POCl_3 + HCl.$$

The hydroxyl group in phenols is replaced with much greater difficulty than that in aliphatic compounds.

5. By the action of phosphorus pentachloride or pentabromide upon aldehydes or ketones. This gives compounds in which two chlorine or bromine atoms are combined with the same carbon atom.



$$\underset{\text{Aldehyde.}}{CH_3C{\overset{\displaystyle /\!\!/ O}{}}\!\!-H} + PCl_5 = \underset{\text{Ethylidene chloride.}}{CH_3CHCl_2} + POCl_3$$

$$\underset{\text{Acetone.}}{CH_3COCH_3} + PBr_5 = CH_3CBr_2CH_3 + POBr_3.$$

6. By the action of cuprous chloride or bromide or hydriodic acid upon a halogen salt of a diazo-compound. (See p. 460). This reaction is extremely useful for the replacement of an amino group by a halogen atom in the aromatic series.

7. By the action of alcoholic potash or soda upon a dihalogen compound. Attention has already been called to the fact that substitution products cannot be obtained from unsaturated compounds directly. The method here given makes it possible to obtain such substitution products indirectly. Thus ethylene gives, with bromine, ethylene bromide, CH_2BrCH_2Br; and this, on treatment with alcoholic potash, loses hydrobromic acid with formation of vinyl bromide (monobromethylene):

$$CH_2BrCH_2Br + KOH = \underset{\text{Vinyl bromide.}}{CHBr=CH_2} + KBr + H_2O.$$

8. By the action of hypochlorites, hypobromites or hypoiodites upon compounds containing the group $COCH_3$, or upon 1,3-diketones. The reaction gives rise only to the formation of chloroform, $CHBr_3$, bromoform, $CHBr_3$, or iodoform, CHI_3. It appears to consist at first in the substitution of halogen for hydrogen in the CH_3 group, followed by a hydrolysis which is closely related to the "acid decomposition" of acetoacetic ester.

$$\underset{\text{Acetone.}}{2CH_3COCH_3} + 3CaO_2Cl_2 = \underset{\text{Trichloracetone.}}{2CH_3COCCl_3} + 3Ca(OH)_2$$

$$2CH_3COCCl_3 + Ca(OH)_2 = Ca(CH_3CO_2)_2 + \underset{\text{Chloroform.}}{2CHCl_3}.$$

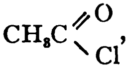
The action of sodium hypochlorite upon dihydroresorcinol has been given (p. 159). This last reaction has not been studied for a sufficient number of cases to make sure that it is general in its application, but it seems likely that it will prove so.

General Properties of Halogen Compounds. — In general, the organic halogen compounds are liquids or solids with boiling points which increase with their molecular weights, or with a decrease of the amount of hydrogen which they contain. Only methyl chloride, CH_3Cl, methyl bromide, CH_3Br, ethyl chloride, C_2H_5Cl and a few fluorine compounds of low molecular weight, are gases at ordinary temperatures.

In general, the halogen compounds resemble, in solubility, the bodies from which they are derived. Halogen substitution products of the hydrocarbons are nearly insoluble in water, but are usually soluble in alcohol, ether, and ligroin.

In chemical conduct, the halogen compounds of carbon differ very markedly from the halogen compounds of other elements. The metallic halides, with very few exceptions, ionize readily in water, and give immediate precipitates with silver nitrate in aqueous and alcoholic solutions, while halogen compounds of the non-metals react more or less violently with water to form halogen acids and acids of the non-metallic elements. Organic halogen compounds, on the contrary, do not ionize to such a degree as to exhibit electrical conductivity in aqueous or alcoholic solutions, and they will react with silver nitrate in only a few cases. On account of these facts the metallic halogen compounds are spoken of as electrolytes, while the organic halogen compounds are usually considered to be non-electrolytes.

A careful study of the matter would seem to indicate, however, that the difference is one of degree rather than of kind. The organic halogen compounds show as great, or even a greater difference, among themselves, than that between organic and inorganic compounds. Acetyl chloride,



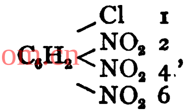
$$CH_3C\begin{matrix}\nearrow\!\!\!\!\nearrow O\\ \searrow Cl\end{matrix},$$

reacts violently with water, and the chlorides of the acids, generally, react in a manner which resembles closely the conduct of the halogen compounds of the non-metallic elements. Methyl iodide, CH_3I, in an alcoholic solution, gives an immediate precipitate with silver nitrate; but chloroform, $CHCl_3$, reacts with silver nitrate very slowly indeed, while monochlorbenzene, C_6H_5Cl, may be boiled with a solution of silver nitrate without the formation of an amount of silver chloride which can be detected. These facts find their most simple explanation by the assumption that organic halogen compounds ionize, but that the degree of ionization is so slight as to be of a different order of magnitude from the ionization of most inorganic compounds.

Differences Between Aromatic and Aliphatic Halogen Compounds. — The difference between methyl iodide and chlorbenzene, referred to above, is a characteristic difference between aliphatic and aromatic compounds. Aliphatic halogen compounds react more or less easily with water, or with silver oxide and water, giving alcohols; with potassium acetate or silver acetate, giving acetyl derivatives of alcohols; with potassium cyanide, giving cyanides, or nitriles; with silver cyanide giving isocyanides; with silver nitrite, giving nitro compounds; with sodium alcoholates, giving ethers; with sodium malonic ester and sodium acetoacetic ester, giving derivatives of these compounds; and with ammonia giving amines.

In general, the iodides react most easily, the chlorides with considerably greater difficulty, while the bromides occupy an intermediate position. The reactivity also decreases with increasing molecular weight, and is greater for primary than for secondary, and for secondary than for tertiary halogen compounds. These general statements are subject, however, to some exceptions and modifications, and the order of reactivity for one reaction is not necessarily that for another. Methyl iodide occupies a somewhat unique position, giving, in some reactions, a rate which is ten-fold that of ethyl iodide.

Aromatic compounds having the halogen in the side chain are to be considered as virtually aliphatic compounds, so far as the reactivity of the halogen atoms is concerned. Thus, benzyl chloride, $C_6H_5CH_2Cl$, reacts readily with potassium cyanide, ammonia, and the other reagents mentioned above. When the halogen is combined with the nucleus, however, it reacts, as a rule, only with very vigorous agents or at a high temperature, as, for instance, with melted caustic potash. In a few cases only, the presence of nitro groups renders a halogen atom more reactive. Thus chlortrinitrobenzene,



$$C_6H_2{<}\begin{matrix}Cl & 1\\ NO_2 & 2\\ NO_2 & 4\\ NO_2 & 6\end{matrix},$$

is changed to picric acid, $C_6H_2(NO_2)_3OH$, by boiling with a solution of sodium carbonate, and to trinitraniline,

$$C_6H_2(NO_2)_3NH_2,$$

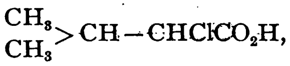
by treatment with ammonia.

Reduction of Halogen Compounds. — By reducing agents, halogen atoms can be replaced by hydrogen, and so the hydrocarbon or mother substance of the halogen derivative regenerated. A great variety of reagents may be employed for the purpose, the most important being sodium amalgam, with water, alcohol, or glacial acetic acid; sodium and moist ether, sodium and absolute alcohol, or amyl alcohol; zinc with water and alcohol, with sulphuric or hydrochloric acid, or with ammonia or sodium hydroxide; and hyriodic acid. With compounds having two halogen atoms combined with adjacent carbon atoms, the first effect of the reduction seems to be merely to remove the halogen. Thus ethylene bromide, CH_2BrCH_2Br, gives ethylene, $CH_2{=}CH_2$, by reduction with zinc and alcohol.

HALOGEN DERIVATIVES OF ACIDS.

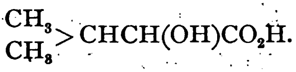
The halogen derivatives of the acids differ in their conduct according to the position of the halogen atom or atoms, and the differences are of considerable practical importance for synthetical purposes and in the study of the structure of unsaturated acids.

α-Halogen Acids. — If the halogen is in the α-position, the compounds are generally more stable than acids with the halogen in the β- or γ-position. By treating α-halogen acids with silver oxide and water, or by boiling them with sodium carbonate or barium hydroxide, or with water alone, α-hydroxy acids can usually be obtained. Thus *α-chlorisovaleric acid* (2 chlor-3-methylbutanoic acid),



$$\begin{matrix}CH_3\\CH_3\end{matrix}\!>CH-CHClCO_2H,$$

gives, with barium hydroxide, α-hydroxyisovaleric acid,

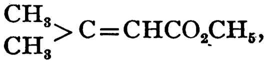


$$\begin{matrix}CH_3\\CH_3\end{matrix}\!>CHCH(OH)CO_2H.$$

The action of alcoholic potash, or of sodium ethylate, on the other hand, usually gives an unsaturated acid. Thus α-bromisovaleric ester,

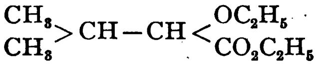
$$\begin{matrix}CH_3\\CH_3\end{matrix}\!>CHCHBrCO_2C_2H_5,$$

gives, with sodium ethylate, C_2H_5ONa, in alcoholic solution, a mixture of dimethylacrylic,



$$\begin{matrix}CH_3\\CH_3\end{matrix}\!>C=CHCO_2CH_5,$$

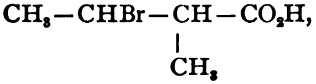
and α-ethoxyisovaleric,



$$\begin{matrix}CH_3\\CH_3\end{matrix}\!>CH-CH<\begin{matrix}OC_2H_5\\CO_2C_2H_5\end{matrix}$$

esters.

β-Halogen Acids are less stable, decomposing more easily on standing or when heated. When warmed with a solution of sodium carbonate there may be formed: an unsaturated hydrocarbon, the halogen acid and carbon dioxide; an unsaturated acid; or a hydroxy-acid. It is sometimes possible to give predominance to one or the other of these decompositions by changing the conditions. The use of only a little more than the calculated amount of sodium carbonate favors the first reaction; the use of an excess of sodium carbonate, or of sodium or barium hydroxide, favors the third reaction (hydroxy acid); while alcoholic potash, or soda, will give chiefly the unsaturated acid. To illustrate, *3-brom-2-methylbutanoic acid*,

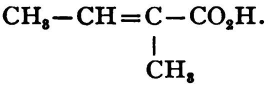


$$CH_3-CHBr-\underset{\displaystyle CH_3}{\underset{|}{CH}}-CO_2H,$$

may decompose to give the following products:

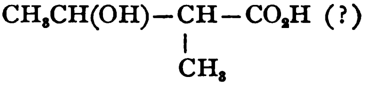
1. $CH_3CH=CH-CH_3$, HBr and CO_2.

2.



$$CH_3-CH=\underset{\displaystyle CH_3}{\underset{|}{C}}-CO_2H.$$

3.

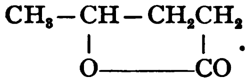


$$CH_3CH(OH)-\underset{\displaystyle CH_3}{\underset{|}{CH}}-CO_2H\ (?)$$

γ-Halogen Acids are, usually, very unstable, and pass spontaneously, or, at most, by boiling with water, into lactones. Thus *γ-bromvaleric acid*,

$$CH_3CHBrCH_2CH_2CO_2H,$$

gives *valerolactone*,



$$\begin{array}{l}CH_3-CH-CH_2CH_2\\ \qquad\ \ |\qquad\qquad\ \ |\\ \qquad\ O\ \text{———}\ CO\end{array}$$

Unsaturated acids may sometimes be obtained from such acids by treating their esters with alcoholic potash or sodium ethylate. Thus *γ-bromisocaproic ester*,

$$\begin{array}{l}CH_3\\CH_3\end{array}>CBrCH_2CH_2CO_2C_2H_5,$$

gives, with sodium ethylate, *pyroterebic ester*,

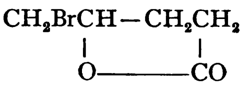
$$\begin{matrix}CH_3\\CH_3\end{matrix}\!>C=CH-CH_2CO_2C_2H_5.$$

Dihalogen derivatives of the acids conduct themselves as is to be expected from the conduct of monohalogen derivatives. Thus:

$$\underset{\text{Crotonic dibromide.}}{CH_3CHBrCHBrCO_2H} \xrightarrow{Na_2CO_3.} \underset{\alpha\text{-Brompropylene.}}{CH_3CH=CHBr}, HBr \text{ and } CO_2;$$

$$\text{" \quad "} \xrightarrow{\text{Alcoholic potash.}} CH_3CH=CBrCO_2H+HBr;$$

$$\underset{\substack{\gamma\text{-}\delta\text{-Dibrom-}n\text{-valeric acid.}\\(4,5\text{-Dibrompentanoic acid}).}}{CH_2BrCHBrCH_2CH_2CO_2H} \xrightarrow{H_2O.}$$



5-Brom 1,4-pentanolid.

Methyl Iodide, CH_3I, is prepared by mixing methyl alcohol with some red phosphorus, adding, in portions, with cooling, eighty to ninety per cent of the calculated amount of iodine, and distilling after some time. Methyl iodide boils at 42.5°, and has a specific gravity of 2.2852 at 15°. It is very reactive, and is extensively used for the introduction of methyl groups in a great variety of organic syntheses.

Methylene Iodide, (diiodomethane) CH_2I_2, is prepared by heating iodoform with hydriodic acid and phosphorus:

$$\underset{\text{Iodoform.}}{CHI_3}+HI=\underset{\text{Methylene iodide.}}{CH_2I_2}+I_2.$$

$$P+5I+4H_2O=H_3PO_4+5HI.$$

Methylene iodide solidifies at 0°, and melts at 4°. It boils, with partial decomposition, at 180°. Its specific gravity is 3.2853 at 15°. It is sometimes used to separate minerals of different specific gravities. Moissan used it to separate diamonds from graphite.

under a pressure of 210 atmospheres, at 0° with a pressure of 620 atmospheres, and at 19.5° with a pressure of 1160 atmospheres.

When sulphuric anhydride acts upon carbon tetrachloride, phosgene and pyrosulphuryl chloride are formed:

$$CCl_4 + 2\ SO_3 = COCl_2 + S_2O_5Cl_2.$$

Ethyl Chloride, CH_3CH_2Cl, is formed very slowly when hydrochloric acid acts upon alcohol. It is prepared by passing hydrochloric acid into alcohol containing anhydrous zinc chloride. It is a gas at ordinary temperatures, but can be easily condensed to a liquid by a freezing mixture, and can be preserved in sealed tubes. It is manufactured on a large scale as a step in the manufacture of "sulfonal" (p. 486). It is also used in producing local anesthesia.

Ethylene Chloride, $CH_2Cl \cdot CH_2Cl$, and **ethylidene chloride,** CH_3CHCl_2, have been considered in the discussion of the structure of ethylene (p. 78).

The following tabular statement of the chlorine derivatives of ethane is of some interest as showing the connection between composition, structure, and physical properties:

NAME.	FORMULA.	BOILING POINT.	SP. GR. AT 0°.
Chlorethane	CH_3CH_2Cl	12.5°	0.9214
1.1.Dichlorethane . .	$CH_3 \cdot CHCl_2$	57.5°	1.2124
1.2.Dichlorethane . .	$CH_2Cl \cdot CH_2Cl$	83.5°	1.2808
1.1.1.Trichlorethane . .	CH_3CCl_3	74.5°	1.3657
1.1.2.Trichlorethane .	$CH_2ClCHCl_2$	114.0°	1.4784
1.1.1.2.Tetrachlorethane,	CH_2ClCCl_3	130.0°	1.5825
1.1.2.2.Tetrachlorethane,	$CHCl_2CHCl_2$	147.0°	1.6258
Pentachlorethane . .	$CHCl_2CCl_3$	161.7°	1.7089
Hexachlorethane . .	CCl_3CCl_3	185.0°	2.011

It will be seen that, of two isomers, the symmetrical compound always has a higher boiling point and a higher specific gravity.

Ethyl Bromide, C_2H_5Br, can be prepared by dropping bromine into a mixture of red phosphorus and ethyl alcohol. It is best prepared by mixing equal weights of ethyl alcohol and concentrated sulphuric acid, adding the mixture, which contains ethyl sulphuric acid, to a mixture of water and potassium bromide, and distilling:

$$C_2H_5HSO_4 + KBr = C_2H_5Br + KHSO_4.$$

Ethyl bromide is a volatile oil with a pleasant odor. It boils at 38.37°, and has a specific gravity of 1.4500 at 15°. It is sometimes used as an anæsthetic, especially for the extraction of teeth. For this purpose red phosphorus, which usually contains arsenic, should not be used in its preparation.

Ethylene Bromide, CH_2BrCH_2Br, is prepared by passing ethylene into bromine till the color of the latter is discharged. It melts at 9.53°, boils at 131.6°, and has a specific gravity of 2.1785 at 20°.

Bromethylene (vinyl bromide) is prepared by the action of alcoholic potash upon ethylene bromide:

$$CH_2BrCH_2Br + KOH = CH_2{=}CHBr + KBr + H_2O.$$

Vinyl bromide boils at 16°, and has a specific gravity of 1.5167 at $\frac{14^\circ}{4^\circ}$. Vinyl bromide is absorbed by concentrated sulphuric acid; and the solution gives, on distillation, crotonic aldehyde, $CH_3CH{=}CH{-}CHO$ (p. 177). (What is the relation between this reaction and the conduct of ethylene toward concentrated sulphuric acid (p. 161)?

Perbromethylene, $CBr_2 = CBr_2$, is formed by the action of bromine upon alcohol or ether, or upon silver acetylide:

$$CH{\equiv}CAg + 6\,Br = CBr_2{=}CBr_2 + AgBr + HBr.$$

Perbromethylene crystallizes in plates which melt at 53°. It is volatile with water vapor.

Ethyl Iodide, C_2H_5I, is prepared from ethyl alcohol, red phosphorus, and iodine. It boils at 72.34°, and has a specific gravity of 1.9433 at 15°.

Normal Propyl Iodide, $CH_3CH_2CH_2I$, is prepared from normal propyl alcohol (from fusel oil), red phosphorus, and iodine. It boils at 102.2°, and has a specific gravity of 1.7427 at $\frac{20^\circ}{4^\circ}$.

Isopropyl Iodide (2-iodopropane), CH_3CHICH_3, is prepared by adding white phosphorus, in portions, to a mixture of glycerol, water, and iodine. The hydriodic acid formed from the interaction of iodine, phosphorus, and water acts upon the glycerol, partly as a reducing agent, and partly to replace the hydroxyl by iodine:

$$CH_2OHCHOHCH_2OH+3\ HI=CH_3CHICH_3+3\ H_2O+I_2.$$

Isopropyl iodide boils at 89.5°, and has a specific gravity of 1.7109 at 15°.

Allyl Bromide (1-brompropene), $CH_2{=}CHCH_2Br$, is prepared from allyl alcohol and phosphorus tribromide, or from allyl alcohol, potassium bromide, sulphuric acid, and water. It boils at 70°–71°, and has a specific gravity of 1.4336 at 17°.

2-Brompropene, $CH_2{=}CBrCH_3$, is prepared by treating propylene bromide, $CH_3CHBrCH_2Br$, with alcoholic potash. It boils at 48°–49°, and has a specific gravity of 1.362 at 20°.

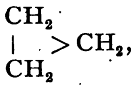
3-Brompropene, $CHBr{=}CHCH_3$ is also formed by treating propylene bromide with alcoholic potash. It boils at

60–61°, and has a specific gravity of 1.428 at 19.5°. What seems to be a stereomeric form is obtained by treating 1.1, 2-tribrompropane, $CH_3CHBrCHBr_2$, with zinc dust and alcohol. It boils at 63°–64°.

Trimethylene Bromide (1,3-dibrompropane),

$$CH_2BrCH_2CH_2Br,$$

is prepared by treating allyl bromide, $CH_2{=}CHCH_2Br$, with hydrobromic acid. It boils at 165°, and has a specific gravity of 1.9228 at $\frac{17.°}{4°}$. It gives cyclopropane,



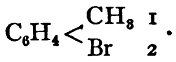
$$\left.\begin{matrix}CH_2\\ |\\ CH_2\end{matrix}\right>CH_2,$$

when treated with zinc dust and alcohol of 75 per cent.

Pinene Hydrochloride, $C_{10}H_{17}Cl$, is formed by passing dry hydrochloric acid into turpentine. It melts at 125°, and boils at 210°. It closely resembles camphor in appearance and odor, and has been called *artificial camphor.*

When pinene hydrochloride is treated with sodium acetate and glacial acetic acid at 200°, *camphene,* $C_{10}H_{16}$, is formed. A molecular rearrangement takes place in the reaction, but its nature is not fully understood.

o-Bromtoluene,

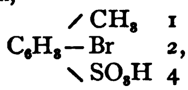


$$C_6H_4\left<\begin{matrix}CH_3 & 1\\ Br & 2\end{matrix}\right..$$

When toluene, to which a little iron has been added, is treated with bromine in the cold, a mixture of ortho- and parabromtoluenes is formed. If this mixture is cooled, the para compound separates in crystals, while the ortho compound remains liquid. The parabromtoluene can be purified by crystallizing from alcohol. The portion remaining liquid after cooling in a freezing mixture consists chiefly of the ortho compound. The pure orthobromtoluene is obtained from ortho-toluidine,

$$C_6H_4<\begin{matrix}CH_3 & 1\\ NH_2 & 2\end{matrix},$$

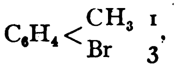
by Sandmeyer's reaction (p. 460), or by distilling orthobromtoluene sulphonic acid,



$$C_6H_3\begin{matrix}\diagup CH_3 & 1\\ -Br & 2,\\ \diagdown SO_3H & 4\end{matrix}$$

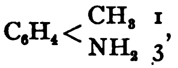
with superheated steam. (Armstrong, *J. Chem. Soc.* (London), 45, 148; Kelbe, *Ber. d. chem. Ges.* 19, 93; Miller, *J. Chem. Soc.*, 61, 1029). Orthobromtoluene melts at −25.9°, boils at 180.6°, and has a specific gravity of 1.4222 at $\frac{20^\circ}{4^\circ}$.

m-Bromtoluene,



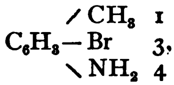
$$C_6H_4<\begin{matrix}CH_3 & 1\\ Br & 3\end{matrix},$$

is prepared from m-toluidine,



$$C_6H_4<\begin{matrix}CH_3 & 1\\ NH_2 & 3\end{matrix},$$

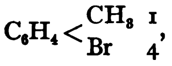
by Sandmeyer's reaction (p. 460), or from metabrompara-toluidine,



$$C_6H_3\begin{matrix}\diagup CH_3 & 1\\ -Br & 3,\\ \diagdown NH_2 & 4\end{matrix}$$

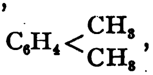
by the elimination of the amino group. It melts at −39.8°, boils at 183.7°, and has a specific gravity of 1.4099 at $\frac{20^\circ}{4^\circ}$.

p-Bromtoluene,



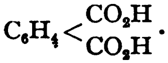
$$C_6H_4<\begin{matrix}CH_3 & 1\\ Br & 4\end{matrix},$$

is prepared by the direct bromination of toluene in the cold (see above). It melts at 28.5°, boils at 185.2°, and has a specific gravity of 1.3898 at $\frac{20^\circ}{4^\circ}$. The three bromtoluenes give the three xylenes,



$$C_6H_4{<}{\begin{matrix}CH_3\\CH_3\end{matrix}},$$

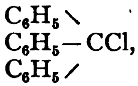
when treated with methyl iodide and sodium; and these, in turn, give, by oxidation, the three phthalic acids,



$$C_6H_4{<}{\begin{matrix}CO_2H\\CO_2H\end{matrix}}.$$

Benzylbromide, $C_6H_5CH_2Br$, is formed by the action of bromine on boiling toluene, best in the direct sunlight. It boils at 198°–199°, and has a specific gravity of 1.4380 at $\frac{22^\circ}{0^\circ}$. It gives, on oxidation, benzoic acid, $C_6H_5CO_2H$.

Triphenylchlormethane,



$$(C_6H_5)_3C{-}Cl,$$

is best prepared by the action of aluminum chloride upon a mixture of benzene and carbon tetrachloride.

$$CCl_4+3C_6H_6+AlCl_3=(C_6H_5)_3CCl+3HCl+AlCl_3.$$

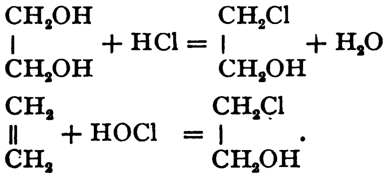
Triphenylchlormethane melts at 108°–112°. It has acquired an especial interest from its use in the preparation of triphenylmethyl, $(C_6H_5)_3C$ (p. 115).

CHLORHYDRINS.

The products formed by the replacement of a part of the hydroxyl groups of glycol, $CH_2OH \cdot CH_2OH$, glycerol, $CH_2OH \cdot CHOH \cdot CH_2OH$, or other polyacid alcohols by halogen atoms, are called *chlorhydrins*, *bromhydrins*, etc.

They may be considered as halogen substitution products of alcohols, and are formed by the treatment of the polyacid alcohols with hydrochloric acid, or by the addition of hypochlorous acid to unsaturated compounds.

Glycol Chlorhydrin (**2-chlor-1-ethanol**), CH_2ClCH_2OH, is prepared by treating glycol with hydrochloric acid, and is also formed by the addition of hypochlorous acid to ethylene:

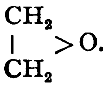


$$\begin{array}{l}CH_2OH\\ |\\ CH_2OH\end{array} + HCl = \begin{array}{l}CH_2Cl\\ |\\ CH_2OH\end{array} + H_2O$$

$$\begin{array}{l}CH_2\\ \|\\ CH_2\end{array} + HOCl = \begin{array}{l}CH_2Cl\\ |\\ CH_2OH\end{array}.$$

It is interesting to notice that in the latter reaction hypochlorous acid separates into Cl and OH, and not into H and OCl, as would be expected of an acid. This fact is probably a clue to some other reactions of hypochlorous acid and of hypochlorites.

Glycol chlorhydrin boils at 130°–131°, and has a specific gravity of 1.2233 at 0°. It is oxidized to chloracetic acid, CH_2ClCO_2H, by the chromic acid mixture. With caustic potash it gives ethylene oxide,



$$\left.\begin{array}{l}CH_2\\ |\\ CH_2\end{array}\right> O.$$

α-Monochlorhydrin (**3-chlor-1,2-propanediol**),

$$CH_2Cl \cdot CHOH \cdot CH_2OH,$$

is prepared by treating glycerol with hydrochloric acid. It boils, with some decomposition, at 213°, without decomposition at 139° under a pressure of 18 mm.

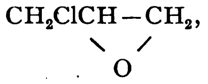
s-Dichlorhydrin, (1,3-dichlor-2-propanol),

$$CH_2ClCHOHCH_2Cl,$$

is prepared by treating glycerol with sulphur chloride.

$$C_3H_8O_3 + 2S_2Cl_2 = C_3H_6Cl_2O + 2HCl + SO_2 + 3S.$$

It is also formed by treating glycerol with hydrochloric acid. It boils at 176°. It is oxidized to chloracetic acid by the chromic acid mixture, and gives epichlorhydrin,



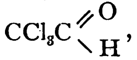
$$CH_2ClCH-CH_2, \quad \text{(bridged by } O\text{)}$$

when treated with solid sodium hydroxide.

Trichlorhydrin (1,2,3-trichlorpropane) is prepared by treating dichlorhydrin with phosphorous pentachloride. It boils at 158°.

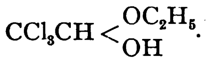
2,4,6-Tribromphenol, $C_6H_2Br_3OH$, is formed by the direct bromination of phenol. It melts at 95°, and sublimes easily.

Chloral (trichloracetaldehyde),



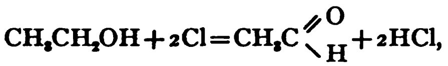
$$CCl_3C\begin{matrix}\nearrow O \\ \searrow H\end{matrix},$$

can be prepared by the chlorination of aldehyde in the presence of considerable water, or of water and calcium carbonate, the latter to neutralize the hydrochloric acid, and prevent its condensing effect on the aldehyde. Practically, chloral is prepared by the action of chlorine upon ethyl alcohol, the final product of the action being chloral alcoholate,



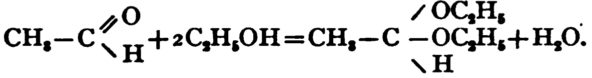
$$CCl_3CH < \begin{matrix} OC_2H_5 \\ OH \end{matrix}.$$

This is then mixed with concentrated sulphuric acid and distilled. The crude chloral is combined with water to chloral hydrate, $CCl_3CH(OH)_2$, which is finally crystallized from carbon bisulphide, chloroform, ligroin, or turpentine. The reactions are probably as follows:



$$CH_3CH_2OH + 2Cl = CH_3C\begin{matrix} /\!\!/ O \\ \diagdown H \end{matrix} + 2HCl,$$

Aldehyde.

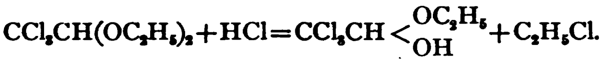


$$CH_3-C\begin{matrix} /\!\!/ O \\ \diagdown H \end{matrix} + 2C_2H_5OH = CH_3-C\begin{matrix} / OC_2H_5 \\ -OC_2H_5 \\ \diagdown H \end{matrix} + H_2O.$$

Acetal (p. 285).

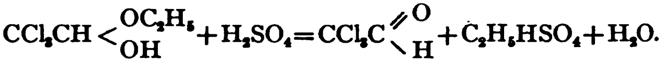
$$CH_3CH(OC_2H_5)_2 + 6Cl = CCl_3CH(OC_2H_5)_2 + 3HCl.$$

Trichloracetal.



$$CCl_3CH(OC_2H_5)_2 + HCl = CCl_3CH < \begin{matrix} OC_2H_5 \\ OH \end{matrix} + C_2H_5Cl.$$

Chloral alcoholate.



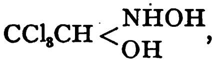
$$CCl_3CH < \begin{matrix} OC_2H_5 \\ OH \end{matrix} + H_2SO_4 = CCl_3C\begin{matrix} /\!\!/ O \\ \diagdown H \end{matrix} + C_2H_5HSO_4 + H_2O.$$

Chloral.

Chloral boils at 97.7°, and has a specific gravity of 1.5121 at $\frac{20^\circ}{4^\circ}$. It does not, itself, mix with water; but it combines with it to form chloral hydrate, $CCl_3CH(OH)_2$, considerable heat being evolved in the reaction. *Chloral hydrate* melts at 57° and is easily soluble in water and alcohols. The vapor density of chloral hydrate shows that, in the gaseous state, it is decomposed into chloral and water. Its magnetic molecular rotation (p. 49) at 54.6°, however, proves that, at that temperature, the water is chemically combined. (Perkin, *J. Chem. Soc.* (London), 51, 809.) It illustrates, again, the retention of two hydroxyl groups by a carbon atom which is combined with a strongly negative group.

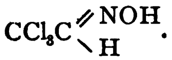
Chloral hydrate is taken in doses of 1.5 to 5 grams to produce sleep. It is also used for the preparation of pure chloroform.

Chloral exhibits the usual characteristics of an aldehyde: nitric acid oxidizes it to trichloracetic acid; it combines with ammonia, and with acid potassium sulphite; with hydroxylamine it forms an addition product,



$$CCl_3CH<\begin{matrix}NHOH\\OH\end{matrix},$$

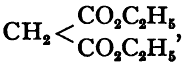
as well as the oxime,



$$CCl_3C\begin{matrix}/\!\!/NOH\\ \diagdown H\end{matrix}.$$

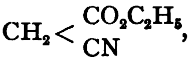
This addition product is of especial interest as indicating that in all cases similar addition products are the first step in the formation of oximes. Also, the possibility of its existence evidently depends on the same property of the molecule as that which makes it possible for two hydroxyl groups to remain combined with the same carbon atom in chloral hydrate.

Monochloracetic Acid, CH_2ClCO_2H, is prepared by the chlorination of acetic acid, acetic anhydride, or acetyl chloride in the direct sunlight, some iodine being added to aid the reaction. The acid melts at 63°, and boils at 185°–187°. It is deliquescent, and very easily soluble in water. It raises blisters on the skin. Monochloracetic acid is used in the laboratory for the preparation of malonic ester,



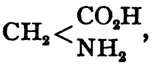
$$CH_2<\begin{matrix}CO_2C_2H_5\\CO_2C_2H_5\end{matrix},$$

cyanacetic ester,



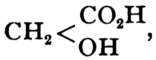
$$CH_2<\begin{matrix}CO_2C_2H_5\\CN\end{matrix},$$

glycocoll (aminoacetic acid),



$$CH_2<\begin{matrix}CO_2H\\NH_2\end{matrix},$$

glycolic acid,



$$CH_2{<}\begin{matrix}CO_2H\\OH\end{matrix},$$

and other compounds. It is now manufactured on a very large scale for use in making artificial indigo (*Ber.* 33, LXXXII.; Address of H. Brunck, at the opening of the Hofmann House in Berlin).

Dichloracetic Acid, $CHCl_2\,CO_2H$, can be obtained by the chlorination of acetic acid, but is most easily prepared by boiling chloral hydrate with a solution of potassium cyanide or potassium ferrocyanide.

$$CCl_3\,CH(OH)_2 + KCN = CHCl_2CO_2H + KCl + HCN.$$

Practically, one part of the molecule is oxidized by the reduction of the other part. Dichloracetic acid melts at —4°, and boils at 189°–191°.

Trichloracetic Acid, CCl_3COOH, can be prepared by the chlorination of acetic acid, but is most easily obtained by the oxidation of chloral hydrate with fuming nitric acid, or with potassium permanganate. Trichloracetic acid melts at 55°, and boils at 195°. When its solution is boiled with alkalies, it decomposes into chloroform and carbon dioxide. The decomposition is closely analogous to the "ketonic" decomposition of acetoacetic acid, and is evidently due to the same cause, — an instability of the molecule caused by the presence of a negative group.

Historical Importance of Trichloracetic Acid. — The discovery of trichloracetic acid by Dumas (*Ann. Chem.* (*Liebig*), 32, 101, (1839)), is of unusual historical interest. It demonstrated that the "positive" hydrogen atoms of acetic acid can be replaced by "negative" chlorine atoms, while the general characteristics of the compound as an acid remain unchanged. Such a result is entirely inconsistent with the dualistic electrochemical theory of chemical compounds which was at that time generally accepted. The discussion which followed finally led to the overthrow of that theory and to a return to a unitary view of chemical compounds.*

Dissociation Constants of the Chloracetic Acids. — While the notion that hydrogen can be replaced by chlorine without changing the general properties of a compound was of the greatest importance at the time, it must not be overlooked that the substitution produces a great change in some of the properties of trichloracetic acid. While methane is formed from acetic acid only by heating it with sodium hydroxide to a comparatively high temperature, trichloracetic acid gives chloroform when simply boiled with caustic potash or even with water. The difference is still more clearly seen in the "strength" of the acids. The values of K (p. 54) are:

Acetic acid	0.00180
Monochloracetic acid	0.155
Dichloracetic acid	5.17
Trichloracetic acid	121.

α-Brompropionic Acid, $CH_3CHBrCO_2H$, is prepared by the direct bromination of propionyl bromide, CH_3CH_2COBr. It melts at 24.5°, and boils at 205.5°. An aqueous solution of its potassium salt gives lactic acid and potassium bromide on standing.

β-Iodopropionic Acid, $CH_2ICH_2CO_2H$, is prepared by heating a mixture of acrylic acid and concentrated hydriodic acid to 130°. It melts at 82°.

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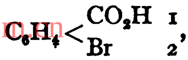
* One of the brightest bits of sarcastic writing in chemical literature appeared, under the pseudonym of S. C. H. Windler, from the pen of Wöhler (*Ann. d. Chem.* (*Liebig*), 33, 308) during this discussion. It is well to remember, however, that both in this case and in the somewhat similar article by Liebig on fermentation (*Ann. d. Chem.* (*Liebig*), 29, 100 (1839)), the views which appeared to the writers as ridiculous are, after all, essentially true.

Orthobrombenzoic Acid,



$$C_6H_4<\begin{matrix}CO_2H & 1\\ Br & 2\end{matrix},$$

can be prepared by oxidizing orthobromtoluene with nitric acid or with potassium permanganate. (Why not with chromic acid?) It melts at 148°.

Metabrombenzoic Acid is prepared by heating benzoic acid with bromine and water in a sealed tube. It melts at 155°.

Parabrombenzoic Acid, may be prepared by oxidizing parabromtoluene with the chromic acid mixture. It melts at 251°.

The three brombenzoic acids may also be prepared from the corresponding amino acids by Sandmeyer's reaction (p. 460).

Laboratory Exercises.

Preparation of the following compounds :

1. Ethyl bromide.
2. Ethylene bromide.
3. Isopropyl iodide.
4. Amyl bromide.
5. p-Dibrombenzene.
6. Benzyl bromide.
7. p-Bromtoluene from toluene and from p-toluidine.
8. Chloroform.
9. α-Brombutyric acid.
10. Trichloracetic acid.
11. Pinene hydrochloride.

CHAPTER XIX.

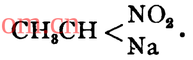
NITRO COMPOUNDS.

Ethyl Nitrite, C_2H_5O-NO. — When a solution of sodium nitrite containing alcohol is dropped into dilute sulphuric acid, ethyl nitrite is formed. It is a very volatile liquid, which boils at 17°. It is decomposed by alkalies very easily with the formation of alcohol and a metallic nitrite, and has all of the properties of a true ester. It is supposed to have the structure given above.

Nitroethane, $C_2H_5NO_2$. — When silver nitrite is treated with ethyl iodide, a mixture of ethyl nitrite and an isomeric compound of totally different properties is formed. This isomeric compound is nitroethane. It boils at 114°–115°. It forms characteristic salts with metals, of which the sodium salt, $C_2H_4NO_2Na$, is an illustration. By reduction it gives ethyl amine, $C_2H_5NH_2$, a fact which indicates that the nitro group is attached to the ethyl by means of the nitrogen atom. When heated with hydrochloric acid it gives hydroxylamine hydrochloride and acetic acid,

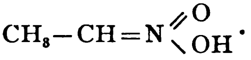
$$CH_3CH_2NO_2+HCl+H_2O=CH_3CO_2H+NH_2\,OH\cdot HCl.$$

Salts of the Nitroparaffins. Pseudo Acids. — Primary and secondary nitroparaffins form salts similar to the sodium nitroethane mentioned above; tertiary nitro compounds (e.g., tertiary nitrobutane $(CH_3)_3C\cdot NO_2$) do not form such compounds. Some authors have supposed that the metal is combined with carbon in these bodies, and formulate sodium nitroethane, as $CH_3CH<^{NO_2}_{Na}$.



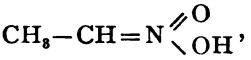
$$CH_3CH<\begin{matrix}NO_2\\ Na\end{matrix}.$$

The facts just given indicate that, while the free nitro compound may, probably, have the structure $CH_3-CH_2-NO_2$, the salts are derived from the tautomeric form, and have the structure,



$$CH_3-CH=N\begin{smallmatrix}/\!\!/O\\ \diagdown OH\end{smallmatrix}.$$

Compounds of this type are called "pseudo" acids, because the free nitro compound is not a true acid at all. Hantzsch has shown (*Ber. d. chem. Ges.* 32, 575), by a study of the electrical conductivity and the reactions with ferric chloride, that when the nitro paraffin (as nitroethane for instance) is liberated from a solution of its salt the isonitro form,

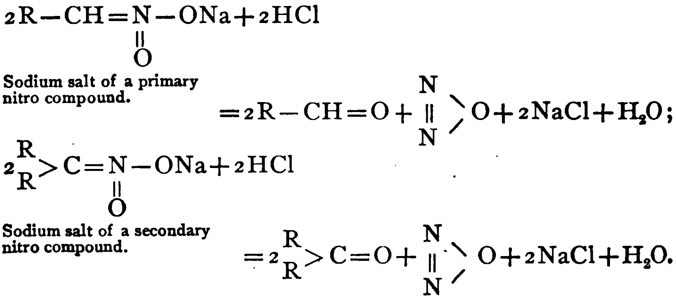


$$CH_3-CH=N\begin{smallmatrix}/\!\!/O\\ \diagdown OH\end{smallmatrix},$$

is at first obtained; but the decreasing conductivity proves that it slowly passes into the true nitro form,

$$CH_3-CH_2-NO_2.$$

The formation of aldehydes and ketones by the decomposition of salts of the nitroparaffins with acids also points very strongly to the constitution given above for those salts (Nef, *Ann. d. Chem.* (*Liebig*), 280, 266):



$$2R-CH=\underset{\underset{O}{\|}}{N}-ONa+2HCl=2R-CH=O+\begin{matrix}N\\ \|\\ N\end{matrix}\!\!>O+2NaCl+H_2O;$$

Sodium salt of a primary nitro compound.

$$2\begin{matrix}R\\ R\end{matrix}\!\!>C=\underset{\underset{O}{\|}}{N}-ONa+2HCl=2\begin{matrix}R\\ R\end{matrix}\!\!>C=O+\begin{matrix}N\\ \|\\ N\end{matrix}\!\!>O+2NaCl+H_2O.$$

Sodium salt of a secondary nitro compound.

Nitro compounds of some of the paraffins and of some cyclic hydrocarbons have been prepared by direct treatment with nitric acid; but, while the method is general and of very great importance for aromatic compounds, it has been comparatively little used for aliphatic and alicyclic bodies. In the aromatic series strong nitric acid, or a mixture of nitric and sulphuric acids, is used. For the nitration of aliphatic compounds, or of homologues of benzene in the side chain, dilute nitric acid seems to be more suitable. (Konowalow, *Ber. d. Chem. Ges.* **28**, 1852, and **29**, 2199; Worstall, however, obtained nitro paraffins by using a stronger acid, *Am. Chem. J.* **20**, 202).

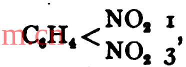
Nitrobenzene, $C_6H_5NO_2$, is prepared, commercially, by allowing benzene to run into a mixture of nitric and concentrated sulphuric acids. According to the proportions used and the temperature at which the nitration takes place, mononitrobenzene or m-dinitrobenzene can be prepared:

$$C_6H_6+HNO_3=C_6H_5NO_2+H_2O.$$

Nitrobenzene is a yellow liquid, which solidifies at a low temperature, and melts at 3°. It boils at 210°. Nitrobenzene has a pleasant odor resembling that of oil of bitter almonds. It is used in perfumery as "essence of mirbane." It is poisonous. It is quite easily volatile with water vapor, readily soluble in alcohol and benzene, only very slightly soluble in water. It can be easily reduced to aniline, $C_6H_5NH_2$, by a variety of reducing agents.

In the nitration of derivatives of benzene. the same laws hold as in the preparation of halogen compounds. The nitro group enters ortho or para to CH_3, C_2H_5, OH, NH_2, Cl, Br, or I and meta to CO_2H, SO_3H, CHO, CN, CCl_3, or NO_2.

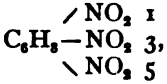
Metadinitrobenzene,



$$C_6H_4<\begin{matrix}NO_2 & 1\\ NO_2 & 3\end{matrix},$$

is readily prepared by the direct nitration of benzene, and its formation is the easiest method of identifying small amounts of benzene. It melts at 91°, and boils at 297°.

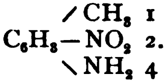
s-Trinitrobenzene,



$$C_6H_3\begin{matrix}/NO_2 & 1\\ -NO_2 & 3,\\ \backslash NO_2 & 5\end{matrix}$$

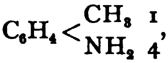
is prepared by heating m-dinitrobenzene for three days at 80°–120° with a mixture of fuming sulphuric acid and nitric acid. It crystallizes in leaflets which melt at 121°–122°.

o-Nitrotoluene is formed, together with the para compound and a trace of the meta derivative, by the direct nitration of toluene. It is prepared pure, by elimination of the amino (NH_2) group from orthonitroparatoluidine,



$$C_6H_3\begin{matrix}/CH_3 & 1\\ -NO_2 & 2.\\ \backslash NH_2 & 4\end{matrix}$$

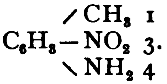
The latter compound is prepared by the nitration of paratoluidine,



$$C_6H_4<\begin{matrix}CH_3 & 1\\ NH_2 & 4\end{matrix},$$

in the presence of a large amount of sulphuric acid, the combination of the sulphuric acid with the amino group giving to it, apparently, the effect of a negative group in the orientation of the nitro group. Orthonitrotoluene melts at —10.5°, and boils at 218°.

m-Nitrotoluene is prepared by the elimination of the amino group, from metanitroparatoluidine,



$$C_6H_3\begin{matrix}/CH_3 & 1\\ -NO_2 & 3.\\ \backslash NH_2 & 4\end{matrix}$$

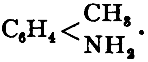
This compound is prepared by the nitration of p-acettoluid,

$$C_6H_4<^{CH_3}_{NHC_2H_3O},$$

and subsequent saponification of the nitroacettoluid formed. Metanitrotoluene melts at +16°, and boils at 230°–231°.

p-Nitrotoluene is prepared by the direct nitration of toluene. The difference in boiling point between the ortho and para compounds is enough in this case, so that they can be partly separated by frictional distillation. The para compound can then be purified by crystallization from alcohol. It melts at 54°, and boils at 238°.

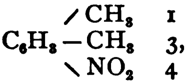
The three nitrotoluenes give, by reduction, three toluidines,



$$C_6H_4<^{CH_3}_{NH_2}.$$

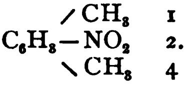
Phenylnitromethane, $C_6H_5CH_2NO_2$, can be prepared by heating toluene with dilute nitric acid (1.12) under pressure. (*Ber.* **28**, 1857; **29**, 699.) It boils at 225°–227°, and has the characteristics of an aliphatic nitro compound, giving a sodium salt which is difficultly soluble in alcohol, and yielding hydroxylamine and benzoic acid when heated with hydrochloric acid. Tin and hydrochloric acid reduce it to *benzyl amine*, $C_6H_5CH_2NH_2$.

Nitroxylenes. — The six nitroxylenes indicated by the theory are all known. The compounds chiefly formed by the nitration of commercial xylene are the *asymmetric nitrometaxylene*,



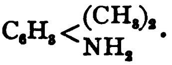
$$C_6H_3\begin{cases}CH_3 & 1\\ CH_3 & 3,\\ NO_2 & 4\end{cases}$$

and *nitroparaxylene*,



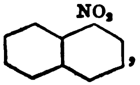
$$C_6H_3\begin{cases}CH_3 & 1\\ NO_2 & 2.\\ CH_3 & 4\end{cases}$$

The nitroxylenes give, by reduction, *xylidines*,



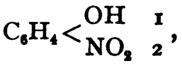
$$C_6H_3<\begin{matrix}(CH_3)_2\\NH_2\end{matrix}.$$

α-Nitronaphthalene,



is formed by the direct nitration of naphthalene. It melts at 61°, and boils at 304°.

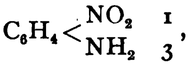
o-Nitrophenol,



$$C_6H_4<\begin{matrix}OH & 1\\NO_2 & 2\end{matrix},$$

is formed by the direct nitration of phenol with nitric acid (1.34). The para compound is formed in smaller amount at the same time. After separating from the nitric acid, the ortho compound passes over, on distillation with water vapor, while the para compound remains behind. Orthonitrophenol melts at 44.27°, and boils at 214°.

m-Nitrophenol is prepared from metanitraniline,



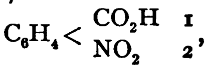
$$C_6H_4<\begin{matrix}NO_2 & 1\\NH_2 & 3\end{matrix},$$

by means of the diazo reaction (p. 460). It melts at 96°, and boils at 194° under a pressure of 70 mm.

p-Nitrophenol is prepared by the direct nitration of phenol (see above). It melts at 114°, and boils with slight decomposition.

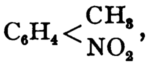
Trinitrophenol, $C_6H_2\overset{1}{O}H\ (\overset{2\ 4\ 6}{NO_2})_3$, or **picric acid** is prepared by treating phenol with an equal weight of sulphuric acid, giving $C_6H_4OH{\cdot}SO_3H$. After dilution with twice its volume of water the solution is further treated with concentrated nitric acid which displaces the sulphonic acid group and introduces nitro groups. Picric acid crystallizes in yellow leaflets which melt at 122.5° and which explode on rapid heating. It is used as a dye and as an explosive. It forms characteristic crystalline compounds with many aromatic hydrocarbons and phenols, and has been often used for the purification and characterization of these compounds.

o-Nitrobenzoic Acid,



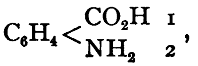
$$C_6H_4 < \begin{matrix} CO_2H & 1 \\ NO_2 & 2 \end{matrix},$$

is prepared by the oxidation of orthonitrotoluene,



$$C_6H_4 < \begin{matrix} CH_3 \\ NO_2 \end{matrix},$$

by means of potassium permanganate. It melts at 147°, and has an intensely sweet taste. It gives anthranilic acid,



$$C_6H_4 < \begin{matrix} CO_2H & 1 \\ NH_2 & 2 \end{matrix},$$

by reduction.

m-Nitrobenzoic Acid. — When benzoic acid is nitrated directly by use of concentrated sulphuric acid and potassium nitrate, a mixture consisting of about 75 per cent of the meta, 22 per cent of the ortho, and 2½ per cent of the paranitrobenzoic acid is formed. The metanitrobenzoic acid melts at 141°–142°.

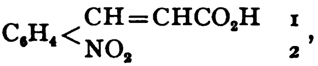
p-Nitrobenzoic Acid is prepared by oxidizing paranitrotoluene with the chromic acid mixture, or, better, with potassium permanganate. It melts at 238°.

Dissociation Constants of Nitrobenzoic Acids. — The electrical conductivity constants of the three nitrobenzoic acids are:

o-Nitrobenzoic acid	$K = 0.616$.
m-Nitrobenzoic acid	$K = 0.0345$.
p-Nitrobenzoic acid	$K = 0.0396$.
Benzoic acid	$K = 0.0060$.

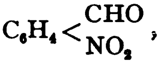
The effect of the nitro group on the strength of the acid, especially when in the ortho position, is very noticeable.

o-Nitrocinnamic Acid,



$$C_6H_4<\begin{matrix}CH=CHCO_2H & 1\\ NO_2 & 2\end{matrix},$$

is prepared, together with the para compound, by the careful nitration of cinnamic acid. It may also be prepared by Perkin's synthesis (p. 244) from o-nitrobenzaldehyde,

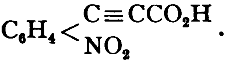


$$C_6H_4<\begin{matrix}CHO\\ NO_2\end{matrix},$$

sodium acetate and acetic anhydride. It melts at 240°. Under proper conditions it gives orthonitrophenyldibrompropionic acid,

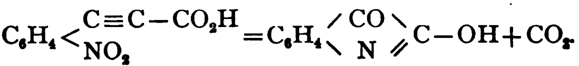
$$C_6H_4<\begin{matrix}CHBrCHBrCO_2H\\ NO_2\end{matrix}.$$

This, with a cold solution of sodium hydroxide, gives *o-nitrophenylpropiolic acid,*



$$C_6H_4<\begin{matrix}C\equiv CCO_2H\\ NO_2\end{matrix}.$$

Orthonitrophenylpropiolic acid decomposes suddenly when heated to 155°–156°. It also decomposes on boiling its aqueous solution, another illustration of instability caused by the presence of negative groups. It gives, by the decomposition, phenylacetylene, $C_6H_5C\equiv CH$, and carbon dioxide. When heated with alkalies it gives isatin:

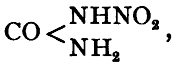


$$C_6H_4<\begin{matrix}C\equiv C-CO_2H\\ NO_2\end{matrix}=C_6H_4\begin{matrix}\diagup CO\diagdown\\ \diagdown\ N\ \diagup\!\!\diagup\end{matrix}C-OH+CO_2.$$

Isatin.

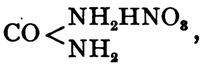
The reduction of nitrophenylpropiolic acid to indigo has been considered (p. 247).

Nitrourea,



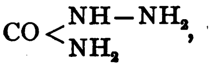
$$CO<\begin{matrix}NHNO_2\\NH_2\end{matrix},$$

is prepared by dissolving nitrate of urea,



$$CO<\begin{matrix}NH_2HNO_3\\NH_2\end{matrix},$$

in ice-cold concentrated sulphuric acid. It can be reduced to semicarbazine (often called semicarbazide),



$$CO<\begin{matrix}NH-NH_2\\NH_2\end{matrix},$$

by means of zinc dust and hydrochloric acid. Semicarbazine has proved very useful as a reagent in working with aldehydes and ketones (p. 179). It is kept in the form of the hydrochloride,

$$CO<\begin{matrix}NHNH_2HCl\\NH_2\end{matrix},$$

which crystallizes in prisms that melt at 173°.

Laboratory Exercises.

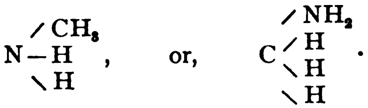
Preparation of the following compounds:

1. Metadinitrobenzene.
2. Ortho and p-nitrotoluenes, and their oxidation to nitro benzoic acids.
3. m-Nitrotoluene.
4. o-Nitro-p-toluidine.
5. α-Nitronaphthalene.
6. m-Nitrobenzoic acid.
7. Semicarbazine hydrochloride.

CHAPTER XX.

AMINES.

Amines or amino * compounds may be considered either as ammonia in which one or more hydrogen atoms have been replaced by a hydrocarbon radical, or as hydrocarbons, or carbon compounds, in which hydrogen has been replaced by the amino (NH_2) group. Thus methyl amine may be written either as



Amines are distinguished as *primary*, *secondary*, or *tertiary*, according as one, two, or three of the hydrogen atoms in ammonia are replaced. There are also *quarternary ammonium bases*, in which the four hydrogen atoms of the ammonium group have been replaced. Thus we have:

Methyl amine (primary)	CH_3NH_2
Dimethyl amine (secondary)	$(CH_3)_2NH$
Trimethyl amine (tertiary)	$(CH_3)_3N$
Tetramethyl ammonium hydroxide . . . (Quaternary ammonium base)	$(CH_3)_4NOH$

Amines are prepared:

1. By the action of halogen alkyls on ammonia.

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* For the distinction between *amino* and *amido* compounds see p. 289.

$$C_2H_5Br + NH_3 = C_2H_5NH_2HBr.$$
$$C_2H_5Br + C_2H_5NH_2 = (C_2H_5)_2NHHBr.$$
$$C_2H_5Br + (C_2H_5)_2NH = (C_2H_5)_3NHBr.$$
$$C_2H_5Br + (C_2H_5)_3N = (C_2H_5)_4NBr.$$

The amines combine with acids to form ammonium salts, as ammonia itself does; and these salts can be decomposed by alkalies with the liberation of the free amine, just as ammonium chloride is decomposed by sodium hydroxide or lime.

The method just given is much less useful than might be expected, because of the formation of a mixture of primary, secondary, and tertiary amines, from which it is difficult to separate pure compounds. This is undoubtedly due to the fact that a portion of the salt of the amine at first formed is at once decomposed by the ammonia still present, and the resulting amine then combines with a second molecule of the alkyl halide, thus:

$$C_2H_5Br + NH_3 = C_2H_5NH_2HBr.$$
$$C_2H_5NH_2HBr + NH_3 = NH_4Br + C_2H_5NH_2$$
$$C_2H_5NH_2 + C_2H_5Br = (C_2H_5)_2NHHBr.$$

2. By the reduction of nitro compounds:

$$\underset{\text{Nitrobenzene.}}{C_6H_5NO_2} + 6\ H = \underset{\substack{\text{Aniline.} \\ \text{(Aminobenzene.)}}}{C_6H_5NH_2} + 2\ H_2O.$$

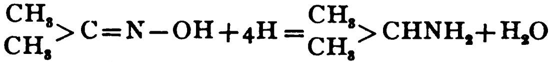
The aromatic nitro compounds are so easily prepared, and so readily reduced, that this method is of much greater importance than any other for the preparation of that class of bodies. The method applies equally, however, to aliphatic and alicyclic nitro compounds.

A great variety of reducing agents are used in special cases. For general laboratory use, and especially for the complete reduction of several nitro groups, tin and hydrochloric acid is, probaby, most common. For technical use, iron and hydrochloric or acetic acid are very important. For acids, and for partial reduction when several nitro groups are present, ammonium sulphide is often useful.

3. By the reduction of cyanides, oximes, and hydrazones:

$$C_6H_5CH_2CN + 4H = C_6H_5CH_2CH_2NH_2$$

Benzyl cyanide. ω-Phenyl ethyl amine.



$$\begin{matrix}CH_3\\CH_3\end{matrix}\!\!>C=N-OH+4H=\begin{matrix}CH_3\\CH_3\end{matrix}\!\!>CHNH_2+H_2O$$

Acetoxime. Isopropyl amine.

$$C_6H_5CH=NNHC_6H_5+4H=C_6H_5CH_2NH_2+C_6H_5NH_2$$

Phenyl hydrazone of benzaldehyde. Benzyl amine. Aniline.

Sodium amalgam, and absolute alcohol with sodium are the most common reducing agents for these compounds.

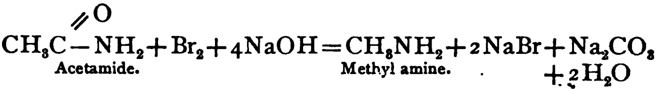
4. By treating an isocyanate with potassium hydroxide,

$$C_2H_5N=C=O+2KOH=C_2H_5NH_2+K_2CO_3.$$

Ethyl isocyanate. Ethyl amine.

This method is of especial interest because it led to the preparation of the first amine. (Wurtz, *Ann. d. Chem.*, (*Liebig*), **71**, 330; **76**, 325.)

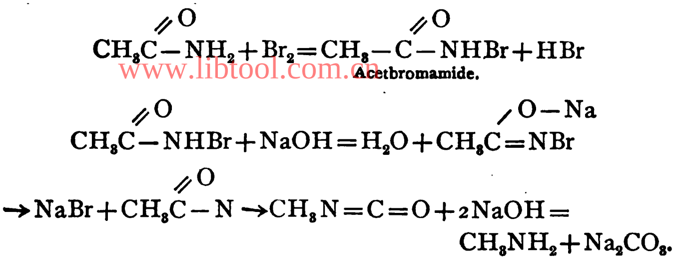
5. By treating an acid amide with bromine and sodium hydroxide, or with sodium hypobromite (Hofmann's reaction):



$$CH_3\overset{\displaystyle /\!\!/O}{C}-NH_2+Br_2+4NaOH=CH_3NH_2+2NaBr+Na_2CO_3+2H_2O$$

Acetamide. Methyl amine.

The reaction, superficially considered, consists simply in the removal of carbonyl (CO), but it is probably closely associated with the preceding method, and depends on the following steps:



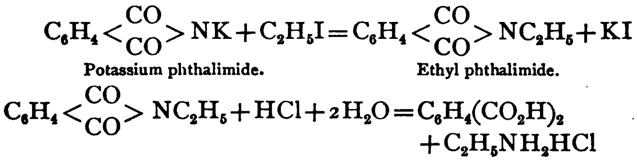
$$CH_3\overset{/\!/O}{C}-NH_2+Br_2=CH_3-\overset{/\!/O}{C}-NHBr+HBr$$

Acetbromamide.

$$CH_3\overset{/\!/O}{C}-NHBr+NaOH=H_2O+CH_3\overset{/O-Na}{C}=NBr$$

$$\rightarrow NaBr+CH_3\overset{/\!/O}{C}-N\rightarrow CH_3N=C=O+2NaOH=CH_3NH_2+Na_2CO_3.$$

6. Treatment of potassium phthalimide with a halogen alkyl followed by a saponification of the resulting alkyl phthalimide:



$$C_6H_4{<}\substack{CO\\CO}{>}NK+C_2H_5I=C_6H_4{<}\substack{CO\\CO}{>}NC_2H_5+KI$$

Potassium phthalimide. Ethyl phthalimide.

$$C_6H_4{<}\substack{CO\\CO}{>}NC_2H_5+HCl+2H_2O=C_6H_4(CO_2H)_2+C_2H_5NH_2HCl$$

This method, which resembles the first above, has the advantage of giving pure primary amines. It depends, partly, on the fact that imides of the acids do not form quaternary compounds.

PROPERTIES OF THE AMINES.

As derivatives of ammonia, and resembling it in general chemical properties, the amines combine with water to form bases,* and with acids to form alkyl ammonium salts. Just as, however, ammonium hydroxide exists only in solution, so only the quaternary ammonium hydroxides can exist otherwise than in solution.

The "strength" of the alkyl ammonium bases varies

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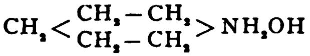
* In the light of our present knowledge, the common statement that ammonia and the amines are themselves bases cannot be considered as true. It is, however, often convenient to speak of the amines as bases, and the common usage will be sometimes followed here.

greatly. It is most accurately measured by means of the electrical conductivity of their aqueous solutions.* The following values may be taken as typical illustrations:

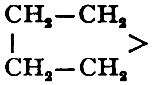
For ammonia, NH_4OH	$K = 0.0023$
For ethyl amine, $C_2H_5NH_3OH$	$K = 0.056$
For diethyl amine, $(C_2H_5)_2NH_2OH$	$K = 0.126$
For triethyl amine, $(C_2H_5)_3NHOH$	$K = 0.064$

Tetrethyl ammonium hydroxide, $(C_2H_5)_4NOH$, is dissociated to the extent of 88 per cent in a solution where $v = 16$; that is, it belongs to the very strong bases.

For allyl amine, $C_3H_5NH_3OH$	$K = 0.0057$
For benzyl amine, $C_6H_5CH_2NH_3OH$	$K = 0.0024$
For piperidine,  $CH_2<\begin{matrix}CH_2-CH_2\\CH_2-CH_2\end{matrix}>NH_2OH$	$K = 0.158$

(See Bredig, *Zeit. f. Phys. Ch.* 13, 289).

The difference in "strength" of the bases is also illustrated qualitatively by their conduct toward weak acids, especially carbonic and acetic acids, and by the conduct of their salts toward water. The alicyclic amines (as *aminocyclopentane*, $\begin{matrix}CH_2-CH_2\\|\\CH_2-CH_2\end{matrix}>CHNH_2$, and aliphatic amines (as ethyl amine, $CH_3CH_2NH_2$) form well-defined carbonates and very stable salts. They can be titrated by means of standard acids with the use of rosolic acid, litmus, or methyl



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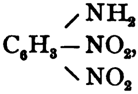
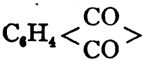
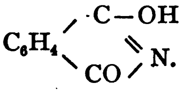
* Strictly speaking, the "strength" of a base should represent the relation between the amounts of the hydroxide and of the ions into which it dissociates. Since, however, larger or smaller quantities of the amine uncombined with water are also present and this fact has not been considered in the calculation of the constants, these may be quite misleading. Thus it is altogether probable that the very much greater apparent "strength" of the tetrethyl ammonium hydroxide is due to the fact that it does not dissociate into amine and water, while the other bases do this to a very large extent. The degree of dissociation into amine and water is also quite independent of the degree of ionization of the hydroxide. See Hantzsch and Sebaldt, *Zeit. f. ph. Chem.* 30, 258; Hantzsch and Kalb, *Ber. d. chem. Ges.* 32, 3109; and Frenzel, *Zeit. anorg. Chem.* 32, 319.

orange as indicators, in the same manner as ammonia. The aromatic amines, in which the amino group is combined with the nucleus, on the other hand, form no carbonates, and, while some of them (as aniline $C_6H_5NH_2$) form stable salts with strong acids, solutions of such salts react acid toward litmus and other indicators, even in the presence of a large excess of the amine. It is evident that in such cases the amount of the base ($C_6H_5NH_3OH$) which can exist in an aqueous solution is vanishingly small. When the negative character of the phenyl group is enforced by the presence of nitro groups or other negative atoms or groups (as in o-nitraniline,  $C_6H_4<\begin{smallmatrix}NH_2 & 1\\ NO_2 & 2\end{smallmatrix}$), the salts often become so unstable that they are decomposed by water, with precipitation of the base. In the case of dinitraniline,  $C_6H_3\begin{smallmatrix}\diagup NH_2\\ -NO_2\\ \diagdown NO_2\end{smallmatrix}$, no salts at all have been prepared. There are, therefore, all degrees of "strength," from the quaternary ammonium bases (as tetraethyl ammonium hydroxide $(C_2H_5)_4NOH$), which resembles the fixed alkalies, to dinitraniline and similar amines, which form no salts. Possibly a truer picture still is given by placing at the other extreme the imides (as phthalimide,  $C_6H_4<\begin{smallmatrix}CO\\ CO\end{smallmatrix}>NH$), in which the hydrogen of the substituted ammonia has acquired distinctly acid properties, though this is probably due to a rearrangement to the form

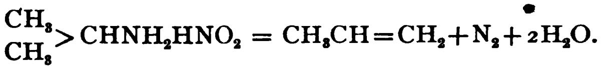


Effect of Nitrous Acid on Amines. — Closely parallel with the basic properties of the amines is the conduct of primary amines toward nitrous acid. The alicyclic amines generally, and the aliphatic amines in some cases, form nitrites which are sufficiently stable to be crystallized, and which decompose but slowly on boiling their neutral or faintly alkaline solutions. The nitrites of aliphatic amines are usually unstable, and decompose in a manner closely analogous to the decomposition of ammonium nitrite:

$$NH_4NO_2 = N_2 + HOH + H_2O;$$

$$C_2H_5NH_2HNO_2 = N_2 + C_2H_5OH + H_2O.$$

The nitrites may also decompose with the formation of unsaturated hydrocarbons:



$$\begin{matrix}CH_3\\CH_3\end{matrix}\!>CHNH_2HNO_2 = CH_3CH{=}CH_2 + N_2 + 2H_2O.$$

Isopropyl ammonium nitrite. Propylene.

Aromatic amines do not, apparently, form nitrites, but give diazo compounds, which will be considered later (p. 456). Diazo compounds may be decomposed with water, giving phenols, and may be considered as an intermediate step in the reaction above, which gives an alcohol. This reaction, in connection with others which have been considered, makes it possible to pass from an alcohol to a homologous alcohol containing one more carbon atom, thus:

$$\begin{aligned}&CH_3CH_2OH \rightarrow CH_3CH_2Br \rightarrow CH_3CH_2CN\\ &\qquad\rightarrow CH_3CH_2CH_2NH_2 \rightarrow CH_3CH_2CH_2OH.\end{aligned}$$

Nitrosamines. — If a salt or an acid solution of a secondary amine is treated with nitrous acid, or with sodium nitrite, a nitrosamine is formed.

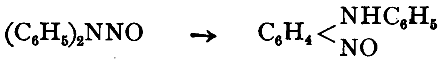
$$(C_2H_5)_2NHHCl + NaNO_2 = (C_2H_5)_2NNO + H_2O + NaCl.$$

Diethylnitrosamine.

The aliphatic nitrosamines are usually yellow liquids, which can be distilled without decomposition, if not of too high molecular weight, and are volatile with water vapor. As they are decomposed by concentrated hydrochloric acid, these properties furnish a means of separating secondary aliphatic amines from primary and tertiary amines, and of preparing them in pure condition.

$$(C_2H_5)_2NNO + HCl + H_2O = (C_2H_5)_2NHHCl + HNO_2.$$

Nitrosamines may also be prepared from secondary aromatic amines. These readily undergo a molecular rearrangement by which the nitroso group is transferred to the benzene nucleus.



$$(C_6H_5)_2NNO \rightarrow C_6H_4{<}\begin{matrix} NHC_6H_5 \\ NO \end{matrix}$$

Nitrosodiphenyl amine. p-Nitrosophenyl aniline.

If a nitrosamine is mixed with phenol and some concentrated sulphuric acid added, on dilution with water, and neutralization with caustic potash or soda, a blue color is obtained. This is known as "Liebermann's reaction," and is useful for the qualitative detection of secondary amines. Nitrosophenol is probably formed by the reaction, and this condenses with more of the phenol, under the influence of the concentrated sulphuric acid, giving a compound which is red in an acid and blue in an alkaline solution.

Tertiary amines do not react readily with nitrous acid, but may, in part, lose one alkyl group and give secondary nitrosamines.

Formation of Isocyanides or Isonitriles. — Primary amines react with chloroform and caustic potash to form isocyanides:

$$C_2H_5NH_2 + CHCl_3 + 3KOH = C_2H_5N{=}C + 3KCl + 3H_2O.$$

The isocyanides can be easily recognized by their execrable odor, and the reaction is useful to distinguish primary from secondary and tertiary amines.

Primary and secondary amines react readily with phenyl sulphonic chloride in the presence of caustic soda. (Schotten-Baumann reaction, p. 282.)

$$C_2H_5NH_2 + C_6H_5SO_2Cl + NaOH = C_6H_5SO_2NHC_2H_5 + NaCl + H_2O.$$

Benzene sulphonic ethyl amide.

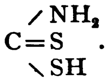
$$(C_2H_5)_2NH + C_6H_5SO_2Cl + NaOH = C_6H_5SO_2N(C_2H_5)_2 + NaCl + H_2O.$$

Benzene sulphonic diethyl amide.

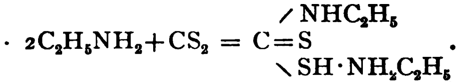
Because of the acid character of the hydrogen of the sulphonamides, the compounds prepared from primary amines are usually soluble in alkalies, while those prepared from secondary amines are not. There are, however, some exceptions, and an excess of the sulphonic chloride must be avoided in the preparation. (Hinsberg, *Ber. d. chem. Ges.* **23**, 2963; **33**, 3526; Solonina, *Central-Blatt*, 1897, II., 848).

Tertiary amines do not react with phenyl sulphonchloride.

Alkyl Isothiocarbamic Acids. Isothiocyanates. — Primary and secondary amines combine directly with carbon bisulphide to form alkyl ammonium salts of alkyl dithiocarbamic acid. Dithiocarbamic acid is



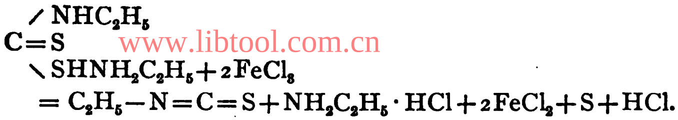
$$C{=}S\begin{cases}NH_2\\SH\end{cases}.$$



$$2C_2H_5NH_2 + CS_2 = C{=}S\begin{cases}NHC_2H_5\\SH\cdot NH_2C_2H_5\end{cases}.$$

Ethyl ammonium ethyl dithiocarbamate.

When the dithiocarbamate formed from a primary amine is warmed with ferric chloride, an isothiocyanate (mustard oil, p. 309) is formed, and can be recognized by its disagreeable odor.



$$C\begin{matrix}\diagup NHC_2H_5\\ =S\\ \diagdown SHNH_2C_2H_5\end{matrix}+2FeCl_3 = C_2H_5-N=C=S+NH_2C_2H_5\cdot HCl+2FeCl_2+S+HCl.$$

The reaction is closely related to the formation of ammonium thiocyanate, $NH_4-N=C=S$, from carbon bisulphide and ammonia.

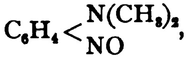
Amines form compounds with chlorplatinic acid, H_2PtCl_6, and chlorauric acid, $HAuCl_4$, which usually crystallize well, and serve excellently for purposes of identification and analysis. Ethyl ammonium chlorplatinate is,

$$(C_2H_5NH_2)_2H_2PtCl_6.$$

Methyl Amine, CH_3NH_2, is most easily prepared from acetamide, CH_3CONH_2, by Hofmann's reaction. It may also be prepared by the reduction of chlorpicrin (nitrochloroform), CCl_3NO_2, or of hydrocyanic acid. It is a gas at ordinary temperatures, and is more soluble than ammonia in water. It has an ammoniacal, fishy odor. Its solution precipitates metallic hydroxides, and the hydroxides of nickel, cobalt, and cadmium do not dissolve in an excess, as they do in ammonia, while aluminium hydroxide dissolves in methyl ammonium hydroxide, but not in ammonium hydroxide. These phenomena are evidently dependent on the fact that methyl ammonium hydroxide is a stronger base than ammonium hydroxide.

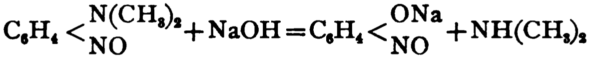
Methyl ammonium chloride is soluble in alcohol, while ammonium chloride is only very slightly soluble. The solubility of the chlorides and other salts of the amines in alcohol is quite general, and is useful for purposes of separation.

Dimethyl Amine, $(CH_3)_2NH$, is most easily prepared from *dimethyl aniline*, $C_6H_5N(CH_3)_2$, which is easily obtained from aniline, $C_6H_5NH_2$, and methyl iodide or methyl chloride. Dimethylaniline gives, with nitrous acid, p-nitrosodimethylaniline,



$$C_6H_4<\begin{matrix}N(CH_3)_2\\NO\end{matrix},$$

and this, when boiled with a solution of sodium hydroxide, is decomposed, giving p-nitrosophenol and dimethylamine.



$$C_6H_4<\begin{matrix}N(CH_3)_2\\NO\end{matrix}+NaOH=C_6H_4<\begin{matrix}ONa\\NO\end{matrix}+NH(CH_3)_2$$

Sodium p-nitroso-phenolate.

Dimethyl amine boils at 7.2°. It mixes with water in all proportions.

Trimethyl Amine, $(CH_3)_3N$, is most easily prepared, in small quantities, by the distillation of tetramethyl ammonium hydroxide,

$$(CH_3)_4NOH=(CH_3)_3N+CH_3OH.$$

Methyl amine, dimethyl amine, and trimethyl amine are all found in herring brine, and are also among the products obtained by the destructive distillation of the residues remaining after preparing alcohol from the molasses of beet sugar. They are also prepared, commercially, by the interaction of methyl chloride or methyl bromide and ammonia. On the other hand, since trimethyl amine gives methyl chloride on heating with hydrochloric acid, the mixture of methyl amines from beet-sugar residues has been used for the commercial preparation of methyl chloride.

$$(CH_3)_3NHCl+3HCl=3CH_3Cl+NH_4Cl.$$

Trimethyl amine boils at 3.2° – 3.8°. It has a penetrating, fishy odor.

Tetramethyl Ammonium Iodide, $(CH_3)_4NI$, is the final product of the action of methyl iodide on ammonia. It is difficultly soluble in cold water, almost insoluble in alcohol, and can be easily purified by crystallization. As tetramethyl ammonium hydroxide cannot be distilled without decomposition, it cannot be prepared by the action of alkalies on tetramethyl ammonium iodide, or other similar salts. By treating a solution of the iodide with silver oxide, however, it can be obtained, and remains as a crystalline mass supposed to have the composition $(CH_3)_4NOH$. At a time when the physical evidence of the existence of ammonium hydroxide in solution was not so well understood as it is at present, this, and the corresponding *tetrethyl ammonium hydroxide*, $(C_2H_5)_4NOH$, were of especial interest as demonstrating the existence of ammonium hydroxide by analogy. The quaternary alkyl ammonium hydroxides are strong bases, resembling the fixed alkalies, potassium and sodium hydroxides, in their general properties.

Ethyl Amines corresponding to the methyl amines are known. Also mixed amines, as dimethyl ethyl amine, $(CH_3)_2\,C_2H_5N$, are known.

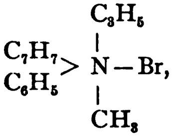
At one time ammonium chloride and many other substances were considered as "molecular compounds," and such formulae as $NH_3 \cdot HCl$, were used, the idea being that the two molecules existed as such in ammonium chloride. According to this conception dimethyldiethyl ammonium iodide should exist in two forms according to the method of preparation, thus:

$$(CH_3)_2C_2H_5N + C_2H_5I = (CH_3)_2C_2H_5N \cdot C_2H_5I$$

$$CH_3(C_2H_5)_2N + CH_3I = CH_3(C_2H_5)_2N \cdot CH_3I.$$

A careful study of the matter has shown that the products formed by the two methods are identical. This can be readily explained only by assuming that the four groups and the halogen atom are combined directly with the nitrogen atom, and that the latter is quinquivalent.

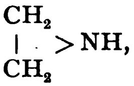
Asymmetry of Nitrogen Compounds. — Another question of considerable interest is, whether an asymmetry like that of carbon (p. 137) is possible for nitrogen compounds. So long as only three atoms or groups are combined with a nitrogen atom asymmetric forms are impossible, if the centers of gravity of the groups lie in the same plane as the nitrogen atom. If the nitrogen atom lies in a different plane from that of the groups, as seems probable (p. 183), asymmetry is possible. No example of such asymmetry in the case of a compound having but three groups combined with the nitrogen atom has, however, been discovered. With five different groups, as in benzylphenylallylmethyl ammonium bromide,



$$\begin{array}{rl} & C_3H_5 \\ & | \\ \begin{matrix}C_7H_7\\C_6H_5\end{matrix}> & N-Br, \\ & | \\ & CH_3 \end{array}$$

asymmetry has been actually established (Pope, *J. Chem. Soc.* [London] 75, 1127).

Vinyl Amine, $CH_2{=}CHNH_2$, or more probably *dimethylene imine,*

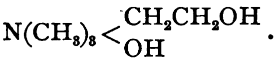


$$\begin{array}{l} CH_2 \\ |\quad >NH, \\ CH_2 \end{array}$$

is prepared by distilling bromethyl ammonium bromide, $CH_2BrCH_2NH_2HBr$, with a strong solution of potassium hydroxide. It is insoluble in water, and boils at 55°–56°. It does not decolorize permanganate, a fact which almost certainly excludes the first formula.

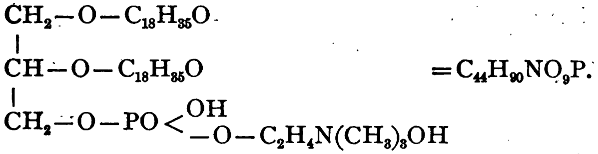
Vinyltrimethyl Ammonium Hydroxide, (neurine), $C_2H_3N(CH_3)_3OH$, is a ptomaine * formed during the putrefaction of meat. It is very poisonous. It has also been prepared synthetically. Its platinum salt, $(C_5H_{12}N_2)_2PtCl_6$, crystallizes in octohedra which melt at 213°–214°.

Ethylol Trimethyl Ammonium Hydroxide (choline),



$$N(CH_3)_3<\begin{matrix}CH_2CH_2OH\\OH\end{matrix}.$$

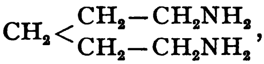
is found in bile, the brain, the yolk of eggs, and other animal substances, combined with palmitic (oleïc, stearic) and glycerol phosphoric acids, as *lecithin*. The lecithin containing only stearic acid and glycerol phosphoric acid, has the structure:



$$\begin{array}{l}CH_2-O-C_{18}H_{35}O\\ \mid\\ CH-O-C_{18}H_{35}O \qquad\qquad\qquad =C_{44}H_{90}NO_9P.\\ \mid\\ CH_2-O-PO<\begin{matrix}OH\\-O-C_2H_4N(CH_3)_3OH\end{matrix}\end{array}$$

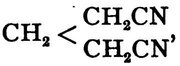
Choline is not poisonous. Choline and neurine have been mutually converted into each other.

Pentamethylene Diamine (cadaverine),



$$CH_2<\begin{matrix}CH_2-CH_2NH_2\\CH_2-CH_2NH_2\end{matrix},$$

is another ptomaïne which has been found among the products of putrefaction of the human cadaver. It has also been prepared by the reduction of trimethylene cyanide,



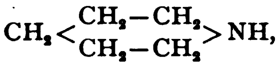
$$CH_2<\begin{matrix}CH_2CN\\CH_2CN\end{matrix},$$

---

* *Ptomaïne* is a name given to basic compounds formed during the decay of animal or vegetable substances, or in the living organism in some diseases. The ptomaïnes occasionally give color reactions resembling those of some poisonous vegetable alkaloids, and render the detection of the latter difficult in toxical analysis.

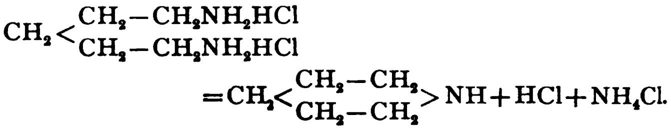
with absolute alcohol and sodium. It solidifies in a freezing mixture, boils at 178°-179°, and has a specific gravity of 0.8784 at 25°. It is not poisonous.

Piperidine (hexahydropyridine or hexazane),

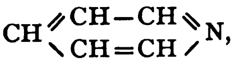


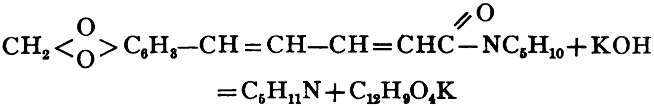
$$CH_2<\begin{matrix}CH_2-CH_2\\CH_2-CH_2\end{matrix}>NH,$$

is formed when cadaverine hydrochloride is distilled.



$$CH_2<\begin{matrix}CH_2-CH_2NH_2HCl\\CH_2-CH_2NH_2HCl\end{matrix}$$
$$=CH_2<\begin{matrix}CH_2-CH_2\\CH_2-CH_2\end{matrix}>NH+HCl+NH_4Cl.$$

It has also been prepared by the reduction of pyridine,  $CH\begin{matrix}/\!\!/CH-CH\backslash\!\!\backslash\\ \backslash CH=CH/\end{matrix}N$, with sodium and absolute alcohol. When piperine, which is found in black pepper, is boiled with alcoholic potash, piperidine and the potassium salt of piperic acid are formed:

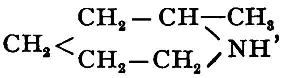


$$CH_2<\begin{matrix}O\\O\end{matrix}>C_6H_8-CH=CH-CH=CHC\overset{/\!\!/O}{}-NC_5H_{10}+KOH$$
$$=\underset{\text{Piperidine.}}{C_5H_{11}N}+\underset{\text{Potassium piperate.}}{C_{12}H_9O_4K}$$

Piperidine has an odor which recalls both that of ammonia and of pepper. It melts at −17°, boils at 106°, and has a specific gravity of 0.8591 at 25°. It mixes with water in all proportions, and the solution is strongly alkaline. With nitrous acid it gives *nitrosopiperidine*, $C_5H_{10}NNO$. When heated with concentrated sulphuric acid to 300°, or with silver acetate and dilute acetic acid to 180°, it is oxidized to pyridine.

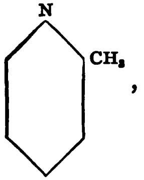
1. (*n*) **Methyl Piperidine,** $C_5H_{10}N-CH_3$, is formed when piperidine and methyl iodide are brought together. It is a liquid which boils at 107°, and has a specific gravity of 0.821 at 15°.

α-Methyl Piperidine (α-pipecolin, 2-methyl hexazane),



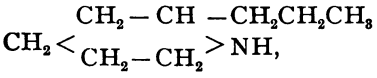
$$\mathrm{CH_2}<\begin{matrix}\mathrm{CH_2-CH-CH_3}\\ \mathrm{CH_2-CH_2}\end{matrix}>\mathrm{NH},$$

is prepared by the reduction of *α-picoline* (*2-methyl pyridine*),



with sodium and absolute alcohol. It boils at 118°, and has a specific gravity of 0.8622 at 0°. It is easily soluble in water, and has an odor like that of piperidine.

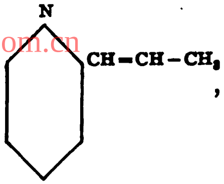
***d*-Coniïne (2-propylpiperidine),**



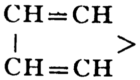
$$\mathrm{CH_2}<\begin{matrix}\mathrm{CH_2-CH-CH_2CH_2CH_3}\\ \mathrm{CH_2-CH_2}\end{matrix}>\mathrm{NH},$$

is found in hemlock, and gives to it its poisonous properties. It has a peculiar penetrating odor, melts at 2.5°, boils at 166°–166.5°, and has a specific gravity of 0.8625 at 0°. $[\alpha]_D = +15.6°$. It is soluble in 90 parts of water, and itself dissolves about one-fourth of its weight of water. It is very poisonous.

***dl*-Coniïne** has been prepared synthetically by the reduction of *2-allylpyridine*,

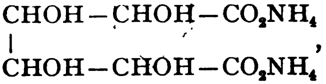


by means of sodium and absolute alcohol. It has been separated into its active constituents by means of the acid tartrate, $C_8H_{17}N{\cdot}H_2C_4H_4O_6$.



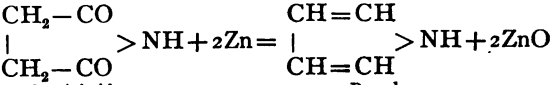
$$\begin{array}{l}CH{=}CH\\ |\qquad\qquad >NH\\ CH{=}CH\end{array}$$

Pyrrol, $\begin{array}{l}CH{=}CH\\ |\qquad >NH\\ CH{=}CH\end{array}$, is found in coal-tar, and in bone-oil. It is formed by the distillation of ammonium saccharate,



$$\begin{array}{l}CHOH-CHOH-CO_2NH_4\\ |\\ CHOH-CHOH-CO_2NH_4\end{array},$$

by passing diethylamine, $(C_2H_5)_2NH$, through a red hot tube, and by reducing succinimide by distilling it with zinc dust.

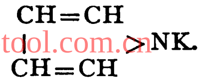


$$\begin{array}{l}CH_2-CO\\ |\qquad\qquad\qquad >NH+2Zn=\\ CH_2-CO\end{array}\begin{array}{l}CH{=}CH\\ |\qquad\qquad\qquad >NH+2ZnO\\ CH{=}CH\end{array}$$

Succinimide. Pyrrol.

Pyrrol may be considered as benzene in which $-CH{=}CH-$ has been replaced by $-NH-$. It boils at 130°–131°, and has a specific gravity of 0.967 at $\frac{21°}{4°}$. Pyrrol is a very weak base, and has a strong tendency to polymerize. It forms pyrrol red, $C_{12}H_{14}N_2O$, when warmed with dilute acids, and tripyrrol, $(C_4H_5N)_3$, when its solution in ether is treated with hydrochloric acid gas and allowed to stand.

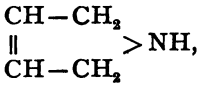
One atom of hydrogen in pyrrol can be replaced by potassium, giving the compound,



$$\left.\begin{array}{l}\mathrm{CH{=}CH}\\ |\\ \mathrm{CH{=}CH}\end{array}\right>\mathrm{NK}.$$

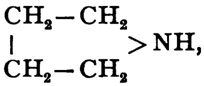
This is decomposed by water, and pyrrol cannot, therefore, be considered as an acid (p. 221).

Pyrrol may be reduced to *pyrroline*,



$$\left.\begin{array}{l}\mathrm{CH-CH_2}\\ \|\\ \mathrm{CH-CH_2}\end{array}\right>\mathrm{NH},$$

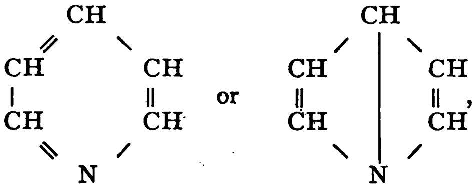
pyrrolidine (*pentazane*),



$$\left.\begin{array}{l}\mathrm{CH_2-CH_2}\\ |\\ \mathrm{CH_2-CH_2}\end{array}\right>\mathrm{NH},$$

and butyl amine, $CH_3CH_2CH_2CH_2NH_2$.

Pyridine,



is found in coal-tar, and in bone-oil. It may be considered as benzene in which one CH group has been replaced by a nitrogen atom, and its formation by the destructive distillation of animal matter is evidently analogous to the formation of benzene from vegetable matter. It is also formed by passing ethylallylamine, $C_2H_5NHC_3H_5$, over litharge heated to 400°–500°, and by warming piperidine (p. 434) with concentrated sulphuric acid to 300°.

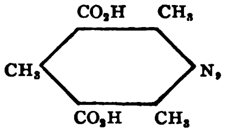
Pyridine boils at 116°, and has a specific gravity of 0.9778 at 25°. It mixes with water in all proportions, and is a very stable substance, resisting the action of even vigorous oxidizing agents. It is only a weak base.

Halogen substitution products, sulphonic acids, carboxyl, hydroxyl, and other derivatives of pyridine, are known. The same general principles of isomerism apply to them as in the case of benzene, with the differences caused by the presence of the nitrogen atom in the ring. Thus there are three monosubstitution products, six bisubstitution products with a single substituent, and ten with two different substituents.

Picolines, $C_5H_4NCH_3$. There are three picolines, which are distinguished as α-, β-, and γ-picoline, or as 1-, 2-, or 3-*methyl-pyridine.* They are found in coal-tar and in bone-oil. They boil respectively at 129°, 143.5°, and 143.5°.

Lutidines, or Dimethyl Pyridines, and Ethyl Pyridines are known in considerable number.

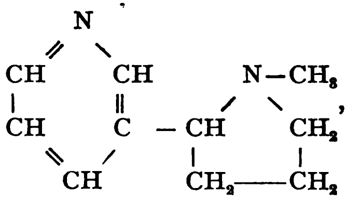
2, 4, 6-Trimethyl Pyridine (γ-collidine) is prepared by distilling a mixture of the potassium salt of collidine dicarboxylic acid,



with calcium hydroxide. It boils at 171°–172°, and has a specific gravity of 0.917 at 15°.

Nicotine,

$C_{10}H_{14}N_2$ or



is found in tobacco, the amount varying from 0.6 to 8.0 per cent. When pure, it does not smell like tobacco. It boils at 247°, and has a specific gravity 1.01101 at $\frac{20^\circ}{4^\circ}$. It mixes with water, alcohol, or ether in all proportions. Nicotine is laevorotatory $[\alpha]_D = -161.55^\circ$. In aqueous solutions the rotation is very much less, and varies with the concentration. Nicotine turns brown, and forms resinous products on exposure to the air. Chromic acid or potassium permanganate oxidize it to *nicotinic acid* (3-*pyridine carboxylic acid*). Nicotine is narcotic in its physiological action, and very poisonous. It forms salts with one or with two molecules of strong monobasic acids. In titrating, with rosolic acid as an indicator, the end point corresponds to the formation of the salt, $C_{10}H_{14}N_2HCl$.

Aniline, $C_6H_5NH_2$, was first obtained by distilling indigo, either alone or with caustic potash. The name is derived from *anil*, the Spanish name for indigo. Aniline is prepared by the reduction of nitrobenzene. In the laboratory, a great variety of reducing agents may be used, the most common being tin and hydrochloric acid, though this is liable to cause its contamination with chlorine compounds. For technical uses, aniline is manufactured in very large quantities by reducing nitrobenzene with iron and hydrochloric or acetic acid.

$$C_6H_5NO_2 + 3Fe + 6HCl = C_6H_5NH_2 + 3FeCl_2 + 2H_2O.$$

In the presence of the chloride or acetate of iron the following reaction may also occur, and much less than the theoretical amount of acid is used:

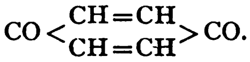
$$C_6H_5NO_2 + 2Fe + 4H_2O = C_6H_5NH_2 + 2Fe(OH)_3.$$

When the reduction is complete, lime is added, and the aniline is distilled with water vapor.

Aniline melts at −8°, boils at 183.7°, and has a specific gravity of 1.024 at 16°. It is soluble in about 30 parts of water, while water, in turn, is soluble in about 20 parts of aniline. Aniline gives a purple color with an aqueous solution of calcium hypochlorite, and a blue color with potassium pyrochromate.

Aniline is a weak base (p. 425). With nitrous acid, in an acid solution, it gives diazobenzene (p. 456). In both respects it differs from the aliphatic and alicyclic amines.

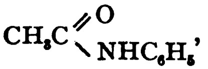
Oxidation with chromic acid converts it partly into quinone,



$$CO<\begin{matrix}CH=CH\\CH=CH\end{matrix}>CO.$$

(p. 209).

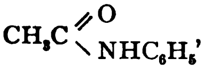
Acetanilide (phenyl acetamide, antifebrine),



$$CH_3C\begin{matrix}\diagup\!\!\diagup O\\ \diagdown NHC_6H_5\end{matrix},$$

is prepared by boiling for some hours a mixture of aniline with one and a half times its weight of glacial acetic acid, in a flask connected with an upright condenser. It may be crystallized from hot water, alcohol, or benzene. It melts at 116°, and boils at 304°. It is used in medicine.

Acetanilide may be considered as *phenyl acetamide*,

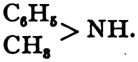


$$CH_3C\begin{matrix}\diagup\!\!\diagup O\\ \diagdown NHC_6H_5\end{matrix},$$

as the *acetyl derivative of aniline*, $C_6H_5NH(C_2H_3O)$, or as the *anilide of acetic acid*, $CH_3CO \cdot NHC_6H_5$. The three designations all refer to an identical structure, of course, but illustrate the fact that it is often practically convenient to use different names for the same compound. In the present case, one name or the other would be more convenient according to whether a study was being made of the amide, the amine, or the acid.

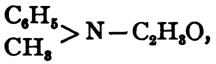
Aniline and its homologues are not very stable toward many reagents, but the acetyl derivatives are much more stable. In many cases, therefore, the aromatic amines may be converted into acetyl derivatives, and the latter may be oxidized, nitrated, or converted into halogen substitution products, to much better advantage than the original amine. The acetyl derivative of the substitution product may then be saponified by boiling with alcoholic potash or with an acid.

Methyl Aniline (phenyl methyl amine),



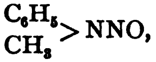
$$\begin{matrix}C_6H_5\\CH_3\end{matrix}>NH.$$

When the sodium salt of acetanilide, $C_6H_5NNa-COCH_3$, is treated with methyl iodide, methyl acetanilide,



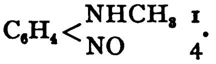
$$\begin{matrix}C_6H_5\\CH_3\end{matrix}>N-C_2H_3O,$$

is formed. This gives, on saponification, methyl aniline, which boils at 193.5°. Methyl aniline gives a nitroso compound,



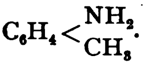
$$\begin{matrix}C_6H_5\\CH_3\end{matrix}>NNO,$$

which readily rearranges itself to p-nitroso methyl aniline,



$$C_6H_4<\begin{matrix}NHCH_3 & 1\\NO & 4\end{matrix}.$$

When methyl aniline hydrochloride, $C_6H_5NHCH_3 \cdot HCl$, is heated in a sealed tube to 300°, the methyl group wanders from the nitrogen to the nucleus, forming p-toluidine,

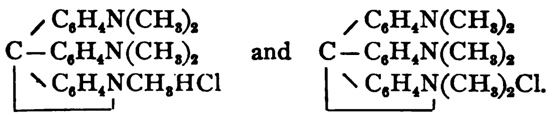


$$C_6H_4<\begin{matrix}NH_2\\CH_3\end{matrix}.$$

The reaction is general in character, methyl or ethyl groups being transferred to the para position, if that is vacant, otherwise to the ortho position; but meta compounds are never formed. This is known as Hofmann's synthesis of aromatic amines, and is of great technical importance, as well as of scientific interest.

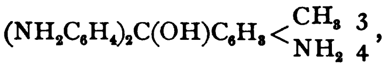
Dimethyl Aniline, $C_6H_5N(CH_3)_2$, is prepared by treating aniline with methyl iodide, or by heating aniline hydrochloride with methyl alcohol to 280°. It boils at 194°, and has a specific gravity of 0.9575 at $\frac{20^\circ}{4^\circ}$.

The para hydrogen atom of the benzene nucleus of dimethyl aniline is very easily attacked by a great variety of agents. Many such reactions give dyestuffs, or substances which may be used in the preparation of dyestuffs, and are technically important. Thus, when dimethyl aniline is treated with chloranil, $C_6Cl_4O_2$, which acts as an oxidizing agent, *methyl violet* is formed. This is a mixture of



$$C\begin{array}{l} / C_6H_4N(CH_3)_2 \\ - C_6H_4N(CH_3)_2 \\ \backslash C_6H_4NCH_3HCl \end{array} \quad \text{and} \quad C\begin{array}{l} / C_6H_4N(CH_3)_2 \\ - C_6H_4N(CH_3)_2 \\ \backslash C_6H_4N(CH_3)_2Cl. \end{array}$$

The close relationship between this body and *rosaniline*,



$$(NH_2C_6H_4)_2C(OH)C_6H_3<\begin{matrix} CH_3 & 3 \\ NH_2 & 4 \end{matrix},$$

is worthy of notice. The latter is prepared by oxidizing a mixture of aniline and o- and p-toluidine with arsenic acid.

Fuchsine, $C_{20}H_{19}N_3 \cdot HCl$, the hydrochloride (or some other salt) of rosaniline, may have a structure like that given for methyl violet, or each may have a quinoid structure (p. 264).

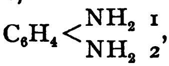
The **Toluidines,** $CH_3C_6H_4NH_2$,

and **Xylidines,** $(CH_3)_2C_6H_3NH_2$,

resemble aniline in general properties, and require no especial consideration here.

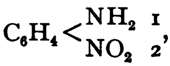
Benzyl Amine, $C_6H_5CH_2NH_2$, is prepared by treating benzyl chloride, $C_6H_5CH_2Cl$, with ammonia, or by treating phenyl acetamide, $C_6H_5CH_2CONH_2$, with potassium hypobromite. It boils at 185°, and has a specific gravity of 0.9826 at $\frac{18.9^\circ}{4^\circ}$. It is a strong base, and resembles the aliphatic amines in its general properties.

o-Phenylene Diamine,



$$C_6H_4<\begin{matrix} NH_2 & 1 \\ NH_2 & 2 \end{matrix},$$

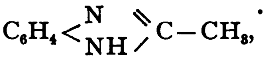
is prepared by the reduction of *orthonitraniline*,



$$C_6H_4<\begin{matrix} NH_2 & 1 \\ NO_2 & 2 \end{matrix},$$

with tin and hydrochloric acid. It melts at 103°, and boils at 256°–258°.

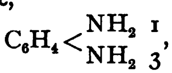
α-Methylbenzimidazole,



$$C_6H_4<\begin{matrix} N \\ NH \end{matrix}>C-CH_3,$$

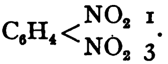
is an anhydride of the acetyl derivative of o-phenylenediamine, formed by boiling it with glacial acetic acid. It melts at 175°, and boils without decomposition. It is a strong base. Similar compounds are formed by other aromatic orthodiamines.

m-Phenylene Diamine,



$$C_6H_4<\begin{matrix} NH_2 & 1 \\ NH_2 & 3 \end{matrix},$$

is prepared by the reduction of m-dinitrobenzene,

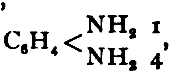


$$C_6H_4<\begin{matrix} NO_2 & 1 \\ NO_2 & 3 \end{matrix}.$$

It melts at 63°, and boils at 282°–284°.

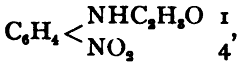
Both ortho- and meta-diamines are characterized by peculiar reactions with nitrous acid (p. 468).

p-Phenylene Diamine,



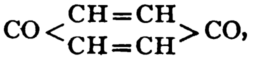
$$C_6H_4{<}\begin{matrix}NH_2 & 1\\ NH_2 & 4\end{matrix},$$

is prepared by the reduction of p-nitracetanilide,



$$C_6H_4{<}\begin{matrix}NHC_2H_3O & 1\\ NO_2 & 4\end{matrix},$$

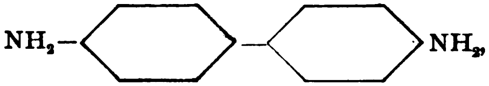
with tin and hydrochloric acid, the acetyl group being removed by the action of the acid during the reduction. It melts at 140°, and boils at 267°. It is easily oxidized to quinone,



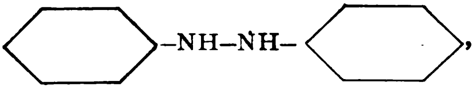
$$CO{<}\begin{matrix}CH{=}CH\\ CH{=}CH\end{matrix}{>}CO,$$

a reaction characteristic of para diamines.

Benzidine (4, 4′-**Diamino diphenyl**),

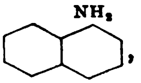


is formed by the rearrangement of hydrazo-benzene,

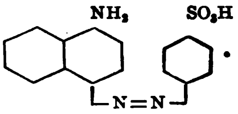


under the action of dilute acids, a reaction of very considerable commercial importance (see p. 474).

***a*-Naphthylamine,**

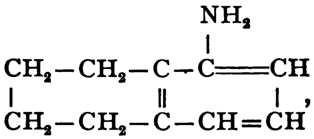


is prepared by the reduction of α-nitronaphthalene. It melts at 50°, and boils at 300°. It "couples" easily with diazobenzene sulphonic acid, and is used for the detection of nitrites in water analysis. The compound formed is *p-sulphobenzene-azo-α-naphthylamine*,



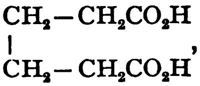
(See p. 469).

Ar*-tetrahydro-α-naphthylamine,



$$\begin{array}{ccccccccc} & & & & & & NH_2 & & \\ & & & & & & | & & \\ CH_2 & - & CH_2 & - & C & - & C & = & CH \\ | & & & & \| & & & & | \\ CH_2 & - & CH_2 & - & C & - & CH & = & CH \end{array},$$

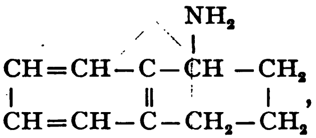
is formed by the reduction of α-naphthylamine by means of amyl alcohol and sodium. It boils at 277°, and has a specific gravity of 1.0625 at 16°. It has the characteristics of an aromatic amine, being a very weak base, and "coupling" easily with diazo compounds. (See above.) Potassium permanganate oxidizes it to adipic,



$$\begin{array}{l} CH_2-CH_2CO_2H \\ | \\ CH_2-CH_2CO_2H \end{array},$$

and oxalic acids.

Ac-tetrahydro-α-naphthylamine,

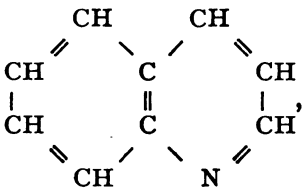


$$\begin{array}{ccccccccc} & & & & & & NH_2 & & \\ & & & & & & | & & \\ CH & = & CH & - & C & - & CH & - & CH_2 \\ | & & & & \| & & & & | \\ CH & = & CH & - & C & - & CH_2 & - & CH_2 \end{array},$$

* The prefixes "ar-" and "ac-" are abbreviations of aromatic and alicyclic, and indicate whether the amino group is connected with the aromatic or alicylic nucleus.

is formed by reducing 1.5 *diaminonaphthylene*, and eliminating the amino group from the aromatic nucleus. It boils at 246.5°. It has the characteristics of an alicyclic amine (p. 424), is a strong base, gives no diazo derivative, does not "couple" with diazo compounds, and gives a stable nitrite. It is oxidized to phthalic acid by potassium permanganate.

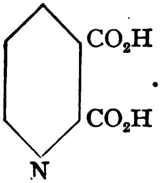
Quinoline,



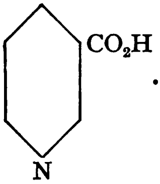
is found in coal-tar, and is formed by the distillation of quinine, cinchonine, or strychnine with potassium hydroxide. It has been prepared synthetically by a number of methods, the most important being Skraup's synthesis, which consists in heating a mixture of aniline, glycerol, sulphuric acid, and nitrobenzene. The nitrobenzene acts chiefly as an oxidizing agent.

$$\underset{\text{Aniline.}}{C_6H_5-NH_2} + \underset{\text{Glycerol.}}{C_8H_8O_8} + O = \underset{\text{Quinoline.}}{C_9H_7N} + 4H_2O$$

Quinoline melts at −19.5°, and boils at 238°. It is oxidized with difficulty, but then forms *quinolinic acid*,



This loses carbon dioxide when heated, and yields *nicotinic acid,*



The latter gives pyridine, of course, when heated with soda lime.

DERIVATIVES OF HYDROXYLAMINE.

Closely related to the amines are the derivatives of hydroxylamine. These are of two classes, α-alkylhydroxylamines, in which the hydrogen of the hydroxyl is replaced by the alkyl group; and β-alkylhydroxylamines, in which the hydrogen of the amino group is replaced.

α-Methyl Hydroxylamine, NH_2OCH_3. — When benzaldoxime and methyl iodide are added to a solution of sodium ethylate, and the mixture is heated for some time, methyl benzaldoxime is formed. This is decomposed by heating with concentrated hydrochloric acid, giving benzaldehyde and α-methyl hydroxylaminechloride:

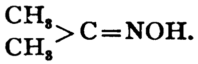
$$C_6H_5CH{=}NOH + C_2H_5ONa = C_6H_5CH{=}NONa + C_2H_5OH$$

$$C_6H_5CH{=}NONa + CH_3I = \underset{\substack{\text{Methyl ester of}\\ \text{benzaldoxime.}}}{C_6H_5CH{=}NOCH_3} + NaI$$

$$C_6H_5CH{=}NOCH_3 + HCl + H_2O = C_6H_5CHO + NH_2OCH_3HCl.$$

The chloride of α-methylhydroxylamine melts at 149°. The chlorplatinate crystallizes in orange-red prisms or plates.

β-Ethyl Hydroxylamine, C_2H_5NHOH. *a-Benzylhydroxylamine*, $NH_2OCH_2C_6H_5$, may be prepared by the methods just given, starting with acetoxime,



$$\begin{matrix}CH_3\\CH_3\end{matrix}>C=NOH.$$

When heated with ethyl bromide, this gives *β-ethyl-a-benzylhydroxylamine:*

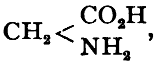
$$NH_2OCH_2C_6H_5 + C_2H_5Br = C_2H_5NHOCH_2C_6H_5HBr.$$

The last compound, when heated with concentrated hydrochloric acid, gives β-ethylhydroxylamine and benzyl chloride:

$$C_2H_5NHOCH_2C_6H_5 + HCl = C_2H_5NHOH + C_6H_5CH_2Cl.$$

The a- and β-derivatives of hydroxylamine show the differences characteristic, in general, of compounds having alkyl groups combined with oxygen, or combined with carbon, nitrogen, sulphur, or other elements. In the former case the alkyl can usually be readily removed as a halogen alkyl compound; in the other cases it cannot. This is illustrated in the last reaction given.

Glycocoll (glycine, aminoacetic* acid),



$$CH_2<\begin{matrix}CO_2H\\NH_2\end{matrix},$$

is formed by boiling gelatine with barium hydroxide or with dilute sulphuric acid, and by boiling hippuric acid with sulphuric acid. It is prepared by treating chloracetic acid, CH_2ClCO_2H, with ammonia. It is soluble in 4.3 parts of of cold water, but is insoluble in absolute alcohol. It melts with decomposition at 232°–236°. It has a sweet taste, and is neutral in reaction. Its chemical properties are indicated

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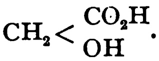
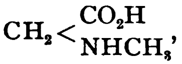
* Sometimes called *amidoacetic acid.* For the nomenclature used in this book see p. 289.

by its structure. It forms salts with both acids and bases, the salts with acids being acid in reaction, those with bases, alkaline. When treated with nitrous acid, it gives glycolic acid,



$$\mathrm{CH_2}<\begin{matrix}\mathrm{CO_2H}\\ \mathrm{OH}\end{matrix}.$$

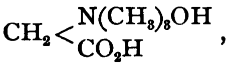
Sarcosine (methylglycocoll),



$$\mathrm{CH_2}<\begin{matrix}\mathrm{CO_2H}\\ \mathrm{NHCH_3}\end{matrix},$$

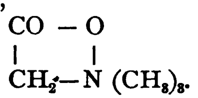
is formed by boiling creatine or caffeïne (p. 298) with barium hydroxide, or by treating chloracetic acid with methyl amine. It melts at 210°–215°.

Trimethylglycocoll (betaïne),



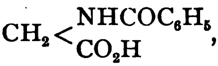
$$\mathrm{CH_2}<\begin{matrix}\mathrm{N(CH_3)_3OH}\\ \mathrm{CO_2H}\end{matrix},$$

is found in cotton seed, in beets, and in a variety of vegetable and animal substances. It is the source of the dimethyl and trimethylamine obtained commercially by the destructive distillation of beet-sugar residues. When heated to 100°, betaïn loses one molecule of water, and forms the cyclic ammonium salt,



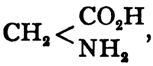
$$\begin{array}{l}\mathrm{CO} - \mathrm{O}\\ \;| \qquad\; |\\ \mathrm{CH_2} - \mathrm{N\,(CH_3)_3}.\end{array}$$

Hippuric Acid (benzoylglycocoll)



$$\mathrm{CH_2}<\begin{matrix}\mathrm{NHCOC_6H_5}\\ \mathrm{CO_2H}\end{matrix},$$

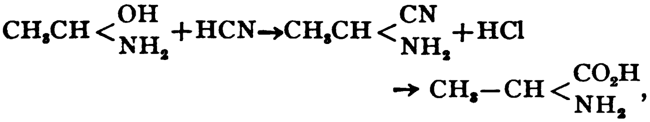
is found in the urine of cattle, horses (whence the name), and other herbivorous animals. If benzoic acid is taken internally, it is secreted in the urine as hippuric acid. It may be prepared by shaking a solution of glycocoll,



$$\mathrm{CH_2}<\begin{matrix}\mathrm{CO_2H}\\ \mathrm{NH_2}\end{matrix},$$

and sodium hydroxide, with benzoyl chloride, C_6H_5COCl. Hippuric acid melts at 187.5°. It is difficultly soluble in cold water, alcohol, and ether. It is decomposed by boiling with mineral acids, or with alkalies, giving glycocoll and benzoic acid.

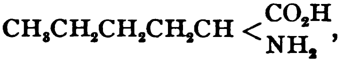
Alanine (**α-aminopropionic acid**), is formed by the action of ammonia upon α-chlorpropionic acid. Of greater interest is its preparation by boiling a solution containing aldehyde ammonia, hydrocyanic acid, and hydrochloric acid. The reaction is general.



$$CH_3CH<\begin{matrix}OH\\NH_2\end{matrix}+HCN\rightarrow CH_3CH<\begin{matrix}CN\\NH_2\end{matrix}+HCl$$

$$\rightarrow CH_3-CH<\begin{matrix}CO_2H\\NH_2\end{matrix},$$

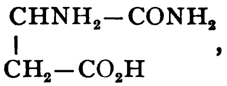
Leucine (**α-aminocaproic acid**),



$$CH_3CH_2CH_2CH_2CH<\begin{matrix}CO_2H\\NH_2\end{matrix},$$

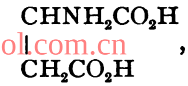
is found in the spleen, pancreas, lymphatic and salivary glands, in the brain, in eggs, and extensively in the animal organism. In some diseases it is found in large amount in the liver. It can be prepared from horn, and has also been made synthetically. The leucine from natural sources is dextrorotatory.

α-Asparagine (**α-aminosuccinamidic acid**),



$$\begin{matrix}CHNH_2-CONH_2\\|\\CH_2-CO_2H\end{matrix},$$

is found in asparagus and in a great variety of plants. It exists in the right, left, and inactive forms, the laevorotatory form being most common in nature. Asparagine gives *aspartic acid*,



$$\begin{array}{l} CHNH_2CO_2H \\ | \\ CH_2CO_2H \end{array},$$

on boiling with acids or bases.

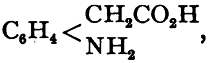
Anthranilic Acid (o-aminobenzoic acid) is formed when indigo is boiled with a solution of potassium hydroxide. It is best prepared by treating phthalamidic acid,

$$C_6H_4<\begin{matrix}CONH_2\\CO_2H\end{matrix}, \text{ or phthalimide, } C_6H_4<\begin{matrix}CO\\CO\end{matrix}>NH,$$

with sodium hypobromite (p. 422). Anthranilic acid melts at 144°–145°. Its solution shows a blue fluorescence, and tastes sweet. It decomposes into carbon dioxide and aniline, on distillation.

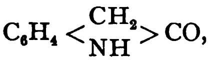
Anthranilic acid has recently acquired a very considerable technical interest from its use in the commercial synthesis of indigo. The proposal for its use depends partly on the fact that naphthalene, which is the commercial starting point in the synthesis, is cheap, and available in very large quantities.

o-Amino-α-Toluic Acid (o-amino phenyl acetic acid),



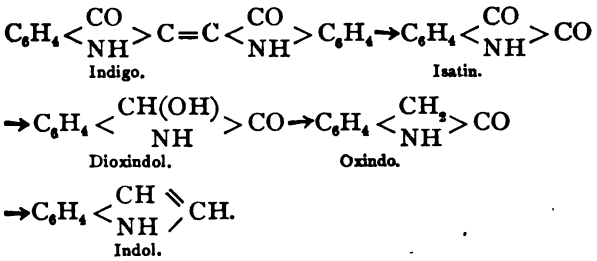
$$C_6H_4<\begin{matrix}CH_2CO_2H\\NH_2\end{matrix},$$

is only known in the form of its salts. When liberated from these it immediately decomposes into water and the anhydride,



$$C_6H_4<\begin{matrix}CH_2\\NH\end{matrix}>CO,$$

which is called *oxindol.* Oxindol possesses especial interest because of its relation to indigo. When indigo is oxidized with nitric acid, it gives isatin; and this gives, by reduction, dioxindol, and by further reduction oxindol, and the last, by distilling with zinc dust yields indol. The relations are as follows:



$$C_6H_4<\begin{matrix}CO\\NH\end{matrix}>C=C<\begin{matrix}CO\\NH\end{matrix}>C_6H_4 \rightarrow C_6H_4<\begin{matrix}CO\\NH\end{matrix}>CO$$

Indigo. Isatin.

$$\rightarrow C_6H_4<\begin{matrix}CH(OH)\\NH\end{matrix}>CO \rightarrow C_6H_4<\begin{matrix}CH_2\\NH\end{matrix}>CO$$

Dioxindol. Oxindo.

$$\rightarrow C_6H_4<\begin{matrix}CH\ \backslash\!\backslash\\NH\ /\end{matrix}CH.$$

Indol.

Isatin was discovered very early in the study of indigo and its derivatives. For some years after that study was begun, the molecular weight of indigo was not known, and isatine seemed, at first, very closely related to indigo. This is clear if we use the empirical formula, and that corresponding to one-half the molecular weight of indigo,

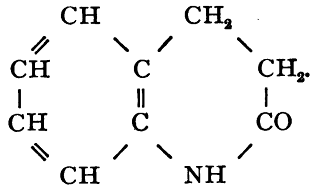
$$\underset{\text{Indigo.}}{C_8H_5NO} \rightarrow \underset{\text{Isatine.}}{C_8H_5NO_2}.$$

It appeared, from this relation, that it should be easy to pass back from isatin to indigo by reduction. The work which was done by Baeyer with this thought in mind led to the series of compounds given above. While this work did not lead to indigo, as had been hoped, it brought the discovery of the use of distillation with zinc dust as a powerful means of reduction. This method led, shortly after, to the reduction of alizarin to anthracene by Graebe and Liebermann, and then to the commercial manufacture of alizarin. (Baeyer, *Ber. d. chem. Ges.* 33, LII.)

o-Amino Hydrocinnamic Acid,

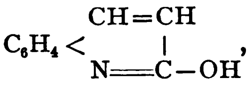
$$C_6H_4<\begin{matrix}CH_2CH_2CO_2H\\NH_2\end{matrix},$$

is also unknown in the free state, as it passes spontaneously into the anhydride, *hydrocarbostyril*,



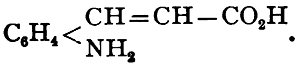
This is formed by the reduction of o-nitrohydrocinnamic acid with tin and hydrochloric acid.

Carbostyril (py-2-hydroxyquinoline),[*]



$$C_6H_4 < \begin{matrix} CH=CH \\ | \\ N{=\!=}C-OH \end{matrix} ,$$

is the "enol" form of the anhydride of *o-aminocinnamic acid*,



$$C_6H_4 < \begin{matrix} CH=CH-CO_2H \\ NH_2 \end{matrix} .$$

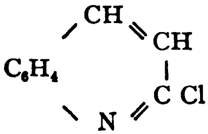
The free acid may be obtained, in this case, by adding ferrous sulphate to a hot ammoniacal solution of *o-nitrocinnamic acid.* It melts at 158°–159°, and its solutions show a bluish green fluorescence.

When, however, o-nitrocinnamic acid is reduced by warming it with ammonium sulphide, carbostyril is formed. This crystallizes from alcohol in large prisms, which melt at 199°–200°. It is a weak base, and also a weak acid, partaking of the character of a phenol, and forming salts which are not decomposed by water, but which are decomposed by car-

---

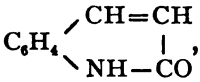
[*] The prefixes "py" and "bz" are abbreviations of pyridine and benzene, used to designate whether a derivative of quinoline has the substituent in the benzene or in the pyridine nucleus.

bonic acid. Treatment with phosphorus pentachloride converts carbostyril into *py-2-chlorquinoline*,

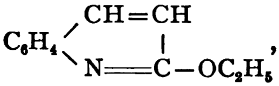


and this can be reduced to quinoline by heating it to 240° with glacial acetic and hydriodic acids.

The ketone form of carbostyril,

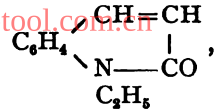


is not known in the free state; but, as often happens, alkyl derivatives of both ketone and enol forms have been prepared. Such alkyl derivatives are stable, while the mother substance may pass readily from one to the other of the "tautomeric" forms. The *ethyl ester of carbostyril*,

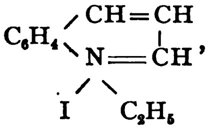


is formed by warming py-2-chlorquinoline (see above) with alcoholic potash, from the silver salt of carbostyril and ethyl iodide, and, together with *ethyl pseudocarbostyril*, by boiling an alcoholic solution of carbostyril with potassium hydroxide, and ethyl iodide. It boils at 266°, and is a strong base. It resembles the phenol ethers in being very stable toward alkalies, but it is decomposed into carbostyril and ethyl chloride by heating with hydrochloric acid to 120°.

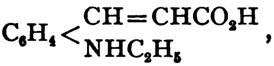
Ethyl Pseudocarbostyril * **(n-ethyl-α-quinolone),**



is formed, in part, by boiling an alcoholic solution of carbostyril with potassium hydroxide and ethyl iodide (see above), or by oxidizing *quinoline iodoethylate,*



with an alkaline solution of potassium ferricyanide. It may be considered as the anhydride of *ethylaminocinnamic acid,*



$$C_6H_4<\begin{matrix}CH=CHCO_2H\\NHC_2H_5\end{matrix},$$

but has not, apparently, been prepared from that compound. Ethyl pseudocarbostyril is not decomposed by heating with hydrochloric acid to 150° (p. 448). It melts at 53°–55°, and boils at 316°–318°.

Laboratory Exercises.

Preparation of the following substances:

1. Diethylamine.
2. Isopropyl amine.
3. 2, 4, 6-Trimethyl-pyridine. (γ-collidine).
4. Aniline.
5. m-Toluidine.
6. Acetanilide.
7. m-Diaminobenzene.
8. p-Diaminobenzene.
9. Benzidine.
10. α-Naphthylamine.
11. Quinoline.
12. Glycocoll.
13. Anthranilic acid.
14. Isatine.

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* The prefix "pseudo" has been proposed by Baeyer to designate substances derived from a form of a compound which does not exist in the free state. As it is sometimes difficult to determine in which of the two tautomeric forms the free substance exists, other designations similar to the second given above are usually to be preferred.

CHAPTER XXI.

DIAZO, AZO, HYDRAZO, AND OTHER NITROGEN COMPOUNDS.

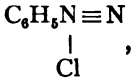
WHEN a cold acid solution of an aromatic amine is treated with nitrous acid, ethyl nitrite, or amylnitrite, a salt of a diazo compound (a "diazonium" salt) is formed,

$$\underset{\text{Aniline hydrochloride.}}{C_6H_5NH_2HCl} + HNO_2 = \underset{\text{Benzene diazonium chloride.}}{C_6H_5N_2Cl} + 2H_2O.$$

Structure of Diazo Compounds. — Early in the study of the diazonium salts, two formulae were proposed for them. Kekulè supposed benzene diazonium chloride to be

$$C_6H_5N{=}NCl,$$

while Blomstrand, Strecker, and Erlenmeyer proposed the formula,

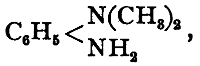


$$\underset{\displaystyle Cl}{\underset{|}{C_6H_5N}}{\equiv}N\ ,$$

which represents them as quaternary ammonium compounds. These formulae have been the occasion of prolonged discussion. Kekulè's formula was thought to explain, more satisfactorily, the "coupling" reactions by which azo compounds are formed. Thus benzene diazonium chloride reacts with many amines and phenols, with elimination of hydrochloric acid, giving azo compounds,

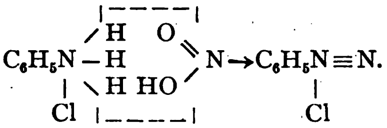
$$C_6H_5N_2Cl + C_6H_5N(CH_3)_2 = \underset{\text{Dimethyl aminoazobenzene.}}{C_6H_5N{=}NC_6H_4N(CH_3)_2} + HCl.$$

That the two groups are combined with different nitrogen atoms in the azo compound is proved by the fact that it gives aniline and p-amino dimethylaniline,



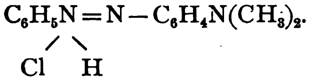
$$C_6H_5<\begin{matrix}N(CH_3)_2\\NH_2\end{matrix},$$

by reduction. Blomstrand's formula, on the other hand, is more in accord with the method of formation of the diazo compounds:



$$\begin{matrix}C_6H_5N\begin{matrix}/H\\-H\\\backslash H\end{matrix}\ \begin{matrix}O\\ \\HO\end{matrix}\!>\!N\rightarrow C_6H_5N\equiv N.\\ |\qquad\qquad\qquad\qquad\quad |\\ Cl\qquad\qquad\qquad\qquad\quad Cl\end{matrix}$$

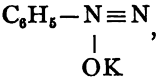
Blomstrand's formula also explains the "coupling" reactions, if we assume an addition at first, giving the compound,



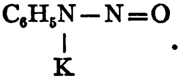
$$C_6H_5N=\underset{Cl\ \ H}{N}-C_6H_4N(CH_3)_2.$$

As the azo compounds are not basic, such a substance would at once split off hydrochloric acid and give the same final result as before.

With alkalies, the diazo compounds also form salts, of which *diazobenzene potassium*, $C_6H_5N_2OK$, is an illustration. When a strongly alkaline solution of diazobenzene potassium is heated, it is changed to *isodiazobenzene potassium*. Three formulae are possible for these salts,

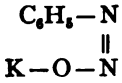


$$C_6H_5-\underset{OK}{\underset{|}{N}}\equiv N,\quad C_6H_5N=N-O-K,$$



$$C_6H_5\underset{K}{\underset{|}{N}}-N=O$$

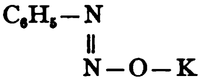
The second formula may also be given the stereomeric forms,



$$\begin{array}{r} C_6H_5-N \\ \| \\ K-O-N \end{array}$$

Syn-diazobenzene potassium.

and



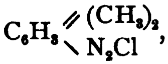
$$\begin{array}{l} C_6H_5-N \\ \quad\;\;\| \\ \quad\;\, N-O-K \end{array}$$

Anti-diazobenzene potassium.

As with the formulae for the chloride, the difficulty of determining whether a given reaction takes place by addition or by substitution, has made the choice among these formulae nearly impossible. A detailed discussion of the questions involved cannot be given here.

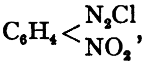
Fortunately, the practical use of the diazo compounds is scarcely affected by the question of their constitution. That practical use is very important, both in the laboratory and in technical manufacture.

The diazo compounds are very unstable, and also very reactive. The salts with acids are often explosive, either by percussion or on heating. In general, the presence of negative groups in the aromatic compound increases their stability, while the presence of positive groups decreases it. Thus the *xylene diazonium chloride*,



$$C_6H_3 \begin{array}{l} /\!\!/ (CH_3)_2 \\ \diagdown N_2Cl \end{array},$$

is less stable, while *p-nitro-benzene diazonium chloride*,



$$C_6H_4 < \begin{array}{l} N_2Cl \\ NO_2 \end{array},$$

is more stable than *benzene diazonium chloride*, $C_6H_5N_2Cl$.

The reactions of the diazo compounds are of two types: those in which the nitrogen is eliminated, and the group is replaced by some atom or group, and those in which the nitrogen atoms are retained, a stable hydrazine, azo compound, or hydrazone, being formed by reduction or "coupling."

REPLACEMENT OF THE DIAZO GROUP.

Because of their instability, diazo compounds are very rarely separated, even in the form of their salts, but are usually prepared at a low temperature (often at 0°) and employed for some further reaction with as little delay as possible. The replacement reactions are to be looked upon as a means of replacing the amino group of aromatic compounds by other atoms or groups. The most important replacement reactions are:

1. **Replacement by Hydrogen.** — This is usually effected by boiling the diazo salt with alcohol:

$$(C_6H_5N_2)_2SO_4 + 2C_2H_5OH = 2C_6H_6 + 2N_2 + 2C_2H_4O + H_2SO_4.$$

Benzene diazonium sulphate. Benzene. Aldehyde.

Usually a cold solution of the amine in absolute alcohol, to which an excess of sulphuric acid has been added, is treated with the mixture of oxides of nitrogen evolved by warming arsenious oxide with nitric acid, or, as is frequently better, with the calculated amount of ethyl nitrite, $C_2H_5-NO_2$. When the diazo compound has been formed, the solution is heated to boiling, and the reaction given above takes place. The reaction is to be considered as a reduction, the alcohol being oxidized. In a few cases other reducing agents have been used, but none of the other methods have acquired considerable importance.

In some instances a second reaction occurs:

$$(C_6H_5N_2)_2SO_4 + 2C_2H_5OH = 2C_6H_5OC_2H_5 + N_2 + H_2SO_4.$$

Ethyl phenyl ether (phenetol).

Whether the diazo group shall be replaced by hydrogen or by the ethoxy $(-O-C_2H_5)$ group, depends partly on the nature of the compound, partly on the conditions of the reaction, as to temperature and pressure, and partly on the nature of the alcohol used. (Remsen, *Am. Chem. J.* **8**, 243; **9**, 387; **11**, 319; **15**, 105.)

2. **Replacement by Hydroxyl.** — This occurs when the diazo compound is formed by adding sodium nitrite, carefully, to a cold, aqueous, acid solution of the amine, and the solution is subsequently boiled,

$$(C_6H_5N_2)_2SO_4 + 2H_2O = 2\underset{\text{Phenol.}}{C_6H_5OH} + N_2 + H_2SO_4.$$

For a clean reaction it is usually important, not only that all of the amine should be converted into the diazo compound, but also that no excess of nitrous acid should be present. This may sometimes be secured by using a slight excess of the sodium nitrite and then adding some urea, which will decompose the excess of nitrous acid when the solution is boiled.

3. **Replacement by Halogens.** — When a strongly acid solution of a diazonium salt is added to a concentrated solution of potassium iodide, and the solution warmed, a nearly quantitative replacement of the diazo group by iodine can usually be secured:

$$\underset{\substack{\text{Benzene diazo-}\\ \text{nium iodide.}}}{C_6H_5N_2I} = \underset{\substack{\text{Iodo-}\\ \text{benzene.}}}{C_6H_5I} + N_2.$$

Similar reactions may occur, to a limited extent, with hydrochloric or hydrobromic acid; but the yields are so small as to make the method practically worthless. The yields may be increased so far as to be satisfactory by a variety of methods, the one having greatest practical significance being known as "Sandmeyer's reaction." This consists in pouring the solution of a diazonium salt into a warm solution of cuprous chloride or cuprous bromide. The most advantageous temperature varies in different cases.

$$C_6H_5N_2Cl + Cu_2Cl_2 = C_6H_5N_2Cl,Cu_2Cl_2 = \underset{\text{Chlorbenzene.}}{C_6H_5Cl} + N_2 + Cu_2Cl_2$$

(Sandmeyer, *Ber. d. chem. Ges.* **17**, 1633, 2650 (1884); **23**, 1880; Erdmann, *Am. Chem.* (Liebig) **272**, 141, (1893).)

Beside the formation of tarry matters, which always occurs to a greater or less extent in connection with diazo reactions, two other reactions may occur which reduce the yield:

$$C_6H_5N_2Cl + H_2O = C_6H_5OH + N_2 + HCl;$$
$$2C_6H_5N_2Cl + Cu_2Cl_2 = \underset{\text{Azobenzene.}}{C_6H_5N{=}NC_6H_5} + 2CuCl_2 + N_2.$$

The first is the usual decomposition of diazonium salts with water, and takes place when the solutions are not properly mixed, while the second seems to be favored by too slow a decomposition of the double compound which is formed when the solutions are mixed.

The diazo group may be replaced by fluorine by adding piperidine to a solution of a diazonium salt, and decomposing the resulting diazo piperidide (see diazo amino compounds p. 464), with concentrated hydrofluoric acid,

$$C_6H_5N_2Cl + \underset{\text{Piperidine.}}{C_5H_{10}{=}NH} = \underset{\text{Diazobenzene piperidide.}}{C_6H_5N{=}N{-}N{=}C_5H_{10}} + HCl$$

$$C_6H_5N{=}N{-}N{=}C_5H_{10} + H_2F_2 = \underset{\substack{\text{Fluor-}\\ \text{benzene.}}}{C_6H_5F} + N_2 + C_5H_{11}N.HF.$$

4. **Replacement by Cyanogen** is also effected by Sandmeyer's reaction, the cuprous chloride solution being replaced by one of cuprous cyanide,

$$C_6H_5N_2Cl + Cu_2C_2N_2 = C_6H_5N_2Cl,Cu_2C_2N_2(?)$$
$$= \underset{\substack{\text{Benzonitrile}\\ \text{(phenyl cyanide).}}}{C_6H_5CN} + N_2 + Cu_2 < \begin{matrix}CN\\ Cl\end{matrix}(?).$$

The nitrile formed can, of course, be saponified to an acid

5. **Replacement by Hydrocarbon Residues** takes place in some cases when diazonium chlorides are heated with aromatic hydrocarbons, pyridine, quinoline, thiophene or similar compounds, with or without the presence of aluminium chloride.

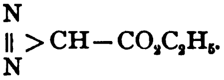
$$C_6H_5N_2Cl + C_6H_6 = \underset{\text{Diphenyl.}}{C_6H_5-C_6H_5} + N_2 + HCl.$$

6. **Replacement by Sulphur, the Sulphonic, Nitro, and other Groups** has been effected in isolated cases, but usually with extremely poor yields, and the methods are of no practical importance.

The second class of reactions for the diazo compounds, in which hydrazines, hydrazones, diazoamino, aminoazo and hydroxyazo ("oxyazo") compounds and diazoimides are formed, will be considered under the head of these various classes of compounds.

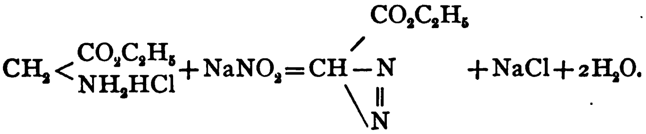
Comparatively few aliphatic diazo compounds are known, and these appear to have a somewhat different structure from the aromatic ones. The most important of them is,

Diazo-acetic Ester,



$$\begin{matrix} N \\ \| \\ N \end{matrix}\!\!>CH-CO_2C_2H_5.$$

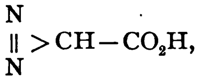
This is formed when the hydrochloride of glycocoll ester is treated with sodium nitrite.



$$CH_2<\begin{matrix}CO_2C_2H_5\\NH_2HCl\end{matrix} + NaNO_2 = CH\begin{matrix}\diagup CO_2C_2H_5 \\ -N \\ \diagdown \| \\ N\end{matrix} + NaCl + 2H_2O.$$

Diazo-acetic ester is a yellow oil which melts at −22°, and boils at 84° under a pressure of 61° mm. It is unstable and liable to explode, especially if impure. It is very reactive, resembling the aromatic diazo compounds in a general way, but it also exhibits some noteworthy differences. It has been used in some important syntheses, and this use seems likely to be extended.

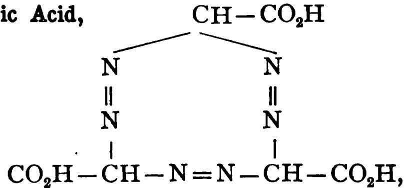
Diazoacetic Acid,



$$\begin{matrix}N\\ \| \\ N\end{matrix}\!>CH-CO_2H,$$

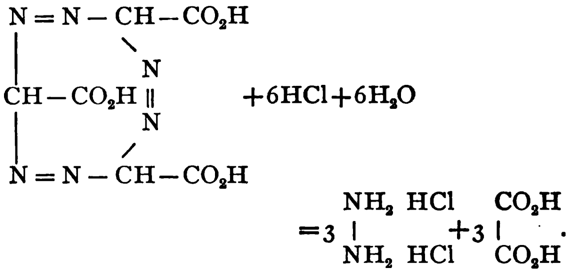
can, apparently, exist only in solutions of its salts, and is even then very unstable.

Triazoacetic Acid,



is obtained in the form of its sodium salt when diazoacetic ester is introduced, slowly, into a very concentrated, hot solution of sodium hydroxide. The free acid crystallizes in yellow plates which decompose at 149°.

Triazoacetic acid is of especial interest because, by its decomposition with acids, hydrazine, H_2N-NH_2, was first prepared.



Hydrazine hydrochloride.

DIAZOAMINO COMPOUNDS.*

If a diazo salt is brought together with an amine in a neutral or faintly acid (acetic acid) solution, a diazoamino compound is formed. The fact that the reaction takes place best in a nearly neutral solution indicates that it is the diazo hydroxide, formed by the hydrolysis of the diazo salt, which takes part in the reaction.

$$\underset{\text{Diazobenzene hydroxide.}}{C_6H_5N_2OH}+\underset{\text{Aniline.}}{C_6H_5NH_2}=\underset{\text{Diazoamino benzene.}}{C_6H_5N=N-NHC_6H_5}+H_2O.$$

It would seem, from the method of formation, that with two different amines two isomeric compounds should be obtained, thus,

$$C_6H_5N=N-NHC_6H_4Br \quad \text{and} \quad BrC_6H_4N=N-NHC_6H_5.$$

It has been found, however, that, no matter which amine is converted into the diazo compound, the same final product results. This has led some to question the explanation of their formation which has been given. It would seem rather that the form at first produced passes at once into the other form, if that is more stable. This may happen thus:

$$C_6H_5N=N-NHC_6H_4Br \rightarrow C_6H_5NH-N(OH)NHC_6H_4Br$$
$$\rightarrow C_6H_5NH-N=N-C_6H_4Br.$$

Another explanation is that the diazo hydroxide has the formula $R-N=N-OH$, in which case the compound $R-NH-N(OH)-NH-R'$ may always be at first formed by addition of the amine to the diazo hydroxide.

The diazoamino compounds are, perhaps, best considered as anilides of the diazo hydroxides, considering the latter as

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* These compounds are often called "diazoamido compounds." It seems better here and in the following pages to retain the distinction between "amino" and "amido" already made (p. 289).

acids. In accordance with this view they may be saponified, in some cases, by careful treatment with acids, giving diazonium salts and amines.

$$C_6H_5N=N-NHC_6H_5+2HBr=C_6H_5N_2Br+C_6H_5NH_2HBr.$$

The diazoamino compounds are usually well crystallized, comparatively stable compounds. They retain, however, a close relationship to the diazo compounds, and most of their reactions are easily understood from that fact. Thus, further treatment with nitrous acid, in an acid solution, converts both parts into a diazo compound; boiling with dilute acids gives, usually, a phenol and an amine:

$$\begin{aligned}&C_6H_5N=N-NHC_6H_5+HCl+H_2O\\&\qquad=C_6H_5OH+N_2+C_6H_5NH_2HCl.\end{aligned}$$

They also form hydroxyazo compounds (see these) with phenols:

$$\begin{aligned}&C_6H_5N=N-NHC_6H_5+C_6H_5-OH\\&\qquad=\underset{\text{p-Hydroxyazobenzene.}}{C_6H_5N=N-C_6H_4OH}+C_6H_5NH_2.\end{aligned}$$

The diazoamino compounds are very weak bases. They form, in some cases, unstable chlorplatinates, as

$$(C_6H_5N_3HC_6H_5)_2H_2PtCl_6.$$

They also yield metallic compounds, as

$$C_6H_5N_3NaC_6H_5.$$

These are usually decomposed by water, but the presence of nitro groups in the benzene nucleus may render them somewhat more stable.

The most important reactions of the diazoamino compounds are those by which they are converted into *aminoazo* bodies. (See below.)

Diazoamino Benzene, $C_6H_5N = N - NHC_6H_5$, is prepared by adding one-half molecule of sodium nitrite to a solution containing one molecule of aniline hydrochloride, and then adding some sodium acetate, keeping the temperature at 25°–30°. It crystallizes from benzene in flat, yellow prisms which melt at 96°.

AMINOAZO COMPOUNDS.*

The aminoazo compounds may be prepared:

1. By nitration and subsequent reduction of azo compounds:

$$\underset{\text{Azobenzene.}}{C_6H_5N{=}N-C_6H_5} \rightarrow \underset{\text{Nitroazobenzene.}}{C_6H_5N{=}N-C_6H_4NO_2}$$

$$\rightarrow \underset{\text{Aminoazobenzene.}}{C_6H_5N{=}N-C_6H_4NH_2}$$

2. By the "coupling" of a diazo compound with an aromatic amine:

$$\underset{\substack{\text{Benzene diazonium}\\ \text{chloride}}}{C_6H_5N_2Cl} + \underset{\text{Dimethyl aniline.}}{C_6H_5N(CH_3)_2} = \underset{\text{p-Dimethylaminoazobenzene.}}{C_6H_5N{=}N-C_6H_4N(CH_3)_2}$$

The azo group enters in the para position with reference to the amino group, if that is free, otherwise in the ortho position. The structure of the resulting compounds can usually be determined by reduction, thus:

$$C_6H_5N{=}NC_6H_4N(CH_3)_2 + 4H$$
$$= C_6H_5NH_2 + \underset{\text{p-Dimethyl phenylene diamine.}}{NH_2-C_6H_4N(CH_3)_2}.$$

That the reaction just given is susceptible of a very great variety of applications is evident. In the benzene series

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* Sometimes called "amidoazo" compounds. The name "azo" is applied to substances containing the group —N=N—. (See p. 472.)

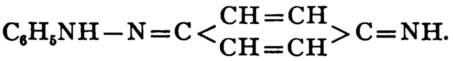
dialkyl-amines and meta-diamines react with especial ease. Naphthylamine and its derivatives also react very easily. For the importance of the reaction in the preparation of dyes, see below under hydroxyazo compounds.

3. By the rearrangement of diazoamino compounds:

$$\underset{\text{Diazoamino benzene.}}{C_6H_5N=N-NHC_6H_5} = \underset{\text{p-Aminoazo benzene.}}{C_6H_5N=N-C_6H_4NH_2}.$$

This is to be considered as merely a special application of the second case, a separation of the diazo group preceding the formation of the aminoazo body.

The aminoazo compounds are weak bases. They form diazo compounds when their acid solutions are treated with nitrous acid, and in most respects conduct themselves as true amines. Some of their properties, however, indicate that they may also exist in a tautomeric quinoid form which may be designated as a hydrazone of a quinonimide, thus:



$$C_6H_5NH-N=C<\begin{matrix}CH=CH\\CH=CH\end{matrix}>C=NH.$$

The difference in color which often exists between the free compounds and their salts may possibly indicate a change from one form to the other.

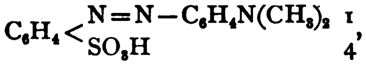
p-Aminoazobenzene, $C_6H_5N = N-C_6H_4NH_2$, is formed by the reduction of p-nitroazobenzene. It is most easily prepared by warming diazoaminobenzene gently with aniline hydrochloride and aniline (see above). It crystallizes in yellow leaflets, which melt at 126°–127°, and boil without decomposition at a temperature above 360°. The great stability, in comparison with the isomeric diazoamino compound, is noteworthy. It gives, by reduction, and in part by merely boiling with hydrochloric acid, aniline, and p-phenylene diamine.

The hydrochloride crystallizes in violet needles.

p-Aminoazobenzene is known as "aniline yellow," and in slightly acid solution it colors silk or wool a deep yellow. Its salts are easily hydrolyzed by water.

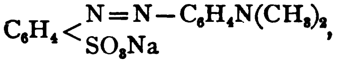
p-Dimethylaminoazobenzene, $C_6H_5N=N-C_6H_4N(CH_3)_2$, prepared from benzene diazonium chloride and dimethylaniline (see above), crystallizes in yellow leaflets, which melt at 117°. The hydrochloride forms very fine purple-red needles.

4-Sulpho-4′-dimethylaminoazobenzene. (The salts are called **Helianthin, Orange III, Tropaölin D**),



$$C_6H_4<\begin{matrix}N=N-C_6H_4N(CH_3)_2\\SO_3H\end{matrix}\quad\begin{matrix}1,\\4'\end{matrix}$$

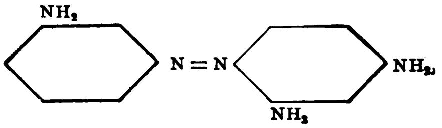
is formed either from p-sulphodiazobenzene and dimethyl aniline, or from p-dimethylaminoazobenzene by treatment with fuming sulphuric acid. It crystallizes in small violet leaflets. The sodium salt,



$$C_6H_4<\begin{matrix}N=N-C_6H_4N(CH_3)_2\\SO_3Na\end{matrix},$$

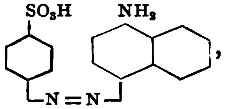
is known as "methyl orange," and is much used as an indicator. This use depends on the fact that the negative ion of the acid, which is present in solutions of its salts, is pure yellow in color, while the free acid is pink. The acid is sufficiently strong so that the salts are scarcely affected by carbonic acid, and the indicator is especially useful in presence of carbonic acid and ammonia. For the same reason it is almost useless for the titration of organic acids.

3,2′,4′-Triaminoazobenzene,

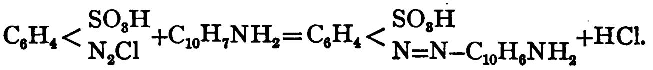


is formed, together with other compounds, when a nitrite is added to a faintly acid solution of m-phenylene diamine. It melts at 143.5°; and it is easily soluble in alcohol and ether, insoluble in ligroin, and difficultly soluble in water. As the compound forms in a very dilute solution of a nitrite, and has a deep yellow color, m-phenylene diamine is sometimes used in the qualitative or quantitative determination of nitrous acid. While one part of nitrogen, as a nitrite, in thirty million of water can be detected by it, the reaction is not sufficiently sensitive for the purposes of water analysis.

p-Sulphobenzene-azo-α-naphthylamine,



is formed when a solution of p-sulphobenzene diazonium chloride is added to a solution of α-naphthylaminechloride.



$$C_6H_4{<}\begin{matrix}SO_3H\\N_2Cl\end{matrix}+C_{10}H_7NH_2=C_6H_4{<}\begin{matrix}SO_3H\\N{=}N{-}C_{10}H_6NH_2\end{matrix}+HCl.$$

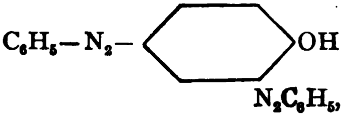
It crystallizes in microscopic needles of a dark violet color. It is almost insoluble in water, very difficultly soluble in alcohol. It forms a red crystalline sodium salt, $C_{16}H_{12}N_3SO_3Na$, which is soluble in water, but almost insoluble in a solution of sodium hydroxide.

As sulphobenzenazonaphthylamine is formed slowly, but almost quantitatively, when sulphanilic acid and naphthylamine hydrochloride are added to dilute solutions containing nitrous acid, and as it imparts to the solutions an intense red color, the reaction is much used in water analysis.

Hydroxyazo (or oxyazo) Compounds.—Diazo compounds "couple" with phenols even more easily than with amines.

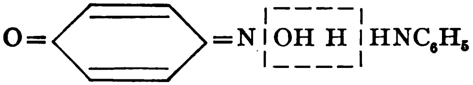
$$C_6H_5N_2OH + \underset{\text{Phenol.}}{C_6H_5OH} = \underset{\text{p-Hydroxyazobenzene.}}{C_6H_5N{=}N{-}C_6H_4OH}$$

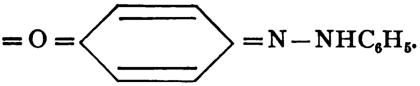
The azo group enters para to the hydroxyl, if that position is free, otherwise in the ortho position. If two molecules of the diazo salt are present for one of the phenol, *hydroxydisazo* compounds are formed. Thus *phenol-2,4-disazobenzene*,



may be prepared in this manner from benzene diazonium nitrate and phenol.

The parahydroxyazo compounds conduct themselves in general as phenols. Since, however, p-hydroxyazobenzene may also be prepared from p-nitrosophenol (quinone monoxime, p. 210) and aniline, it seems probable that they may have, in some cases, and perhaps often, a quinoid structure.





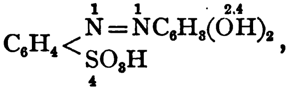
This makes the hydroxyazo compounds hydrazones of the quinones. The orthohydroxyazo compounds exhibit less of the phenol character than the para compounds, and conduct themselves as hydrazones of orthoquinones.

p-Hydroxyazobenzene (**oxyazobenzene**),

$$C_6H_5N{=}N{-}C_6H_4OH.$$

is formed by adding a solution of potassium or sodium nitrite to a dilute solution containing equal parts of phenol and aniline nitrate. It crystallizes in orange-colored rhombic prisms, and melts at 152°.

4-Sulpho-2′,4′-dihydroxyazobenzene,

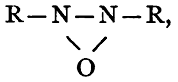


$$C_6H_4<\begin{matrix}\overset{1}{N}=\overset{1}{N}C_6H_3(\overset{2.4}{OH})_2\\ \underset{4}{SO_3H}\end{matrix},$$

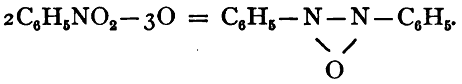
is formed from p-sulphodiazobenzene and resorcinol. Its sodium salt is known as "Crysoin," or "Tropaölin O."

AZOXY COMPOUNDS.

The azoxy compounds,



are isomeric with the hydroxyazo compounds, and much less important. They are formed by the reduction of nitro compounds by boiling with alcoholic potash, by treatment with sodium amalgam, or with a solution of stannous chloride in sodium hydroxide,



Azoxybenzene.

Mild reducing agents convert the azoxy compounds into azo or hydrazo derivatives, more vigorous reduction converts them into amines. Concentrated sulphuric acid converts them into hydroxyazo compounds (see Lachman, *J. Am. Chem. Soc.* **24**, 1178).

AZO COMPOUNDS.

Bodies containing the group $R-N=N-R$ are called azo compounds. The preparation of such substances by means of diazo compounds has just been considered. What may be regarded as the mother substances are prepared by the reduction of nitro compounds, usually by means of zinc dust and alcohol:

$$\underset{\text{Nitrobenzene.}}{2C_6H_5NO_2}+8H = \underset{\text{Azobenzene.}}{C_6H_5N=NC_6H_5}+4H_2O.$$

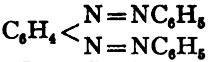
In some cases it is practically easier to carry the reduction a step farther, causing the formation of hydrazo compounds, and to oxidize the latter to azo derivatives.

Azo compounds may also be formed by the oxidation of amines, and by the action of nitroso compounds on amines:

$$2C_6H_5NH_2+2O = C_6H_5N=NC_6H_5+2H_2O$$

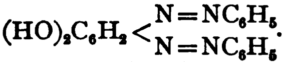
$$\underset{\text{Nitrosobenzene.}}{C_6H_5NO}+C_6H_5NH_2 = C_6H_5N=NC_6H_5+H_2O.$$

Substances containing two azo groups are called "disazo" compounds, thus:



$$C_6H_4<\begin{matrix}N=NC_6H_5\\N=NC_6H_5\end{matrix}$$

Benzenedisazobenzene.



$$(HO)_2C_6H_2<\begin{matrix}N=NC_6H_5\\N=NC_6H_5\end{matrix}.$$

Resorcinoldisazobenzene.

The azo group gives to substances containing it neither acid nor basic properties. There is no replaceable hydrogen connected with the nitrogen, or with an adjacent carbon atom; and the nitrogen retains so slight an affinity for acids that compounds with the halogen acids can only be formed when water is excluded.

Reduction converts azo compounds at first to hydrazo compounds and then to amines.

$$C_6H_5N=NC_6H_5+2H = \underset{\text{Hydrazobenzene.}}{C_6H_5NH-NHC_6H_5}$$

$$C_6H_5NH-NHC_6H_5+2H = 2C_6H_5NH_2.$$

Comparatively few aliphatic azo compounds are known, and these require no especial mention.

The azo compounds are always deeply colored.

Azobenzene, $C_6H_5N=NC_6H_5$, is prepared by the reduction of nitrobenzene with zinc dust and sodium hydroxide in an alcoholic solution, or by the oxidation of hydrazobenzene by the air, or by nitrous acid. It crystallizes in orange yellow leaflets, which melt at 68°, and boil at 293°. Solutions of azobenzene have a deep orange color, but it is not a dye (see below).

HYDRAZO COMPOUNDS.

Hydrazo compounds have the general formula $R-NH-NH-R$, and are prepared by the reduction of nitro compounds or of azo compounds:

$$2C_6H_5NO_2+10H = \underset{\text{Hydrazobenzene.}}{C_6H_5NH-NHC_6H_5}+4H_2O$$

$$C_6H_5N=NC_6H_5+2H = C_6H_5NH-NHC_6H_5.$$

The hydrazo compounds are colorless. As many other colored bodies give colorless compounds by reduction, a general name, "leuco" (from λευκός, white), has been proposed to designate such substances. The hydrazo compounds are the "leuco" compounds corresponding to the azo bodies.

The aromatic hydrazo compounds are not basic in their properties, but mixed hydrazo bodies having on one side an aliphatic or alicyclic residue, may be weak bases.

When heated with dilute acids the hydrazo bodies undergo a highly interesting and commercially very important change, known as the benzidine rearrangement:

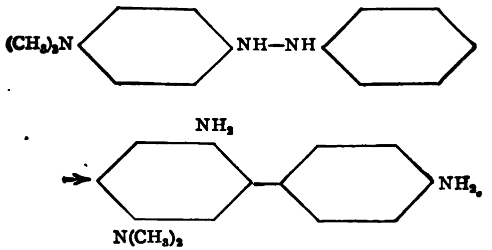
$$C_6H_5NH-NHC_6H_5 = NH_2C_6H_4-C_6H_4NH_2.$$

Benzidine
(4,4'-Diamino diphenyl.)

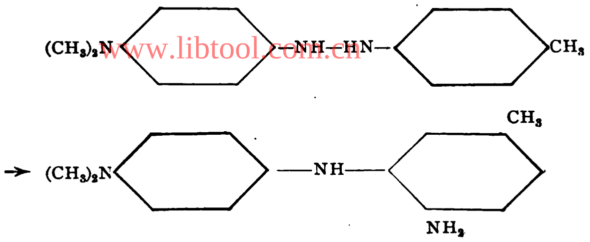
In many cases the reduction and rearrangement of the azo compounds may be carried out simultaneously by the action of an acid, alcoholic solution of stannous chloride.

If the para position is free, the phenyl groups unite chiefly in that position, and the reaction is to be considered as another illustration of the loosening effect exerted by the amino group upon a hydrogen atom in the para position (pp. 209 and 466).

If the para position is occupied, the rearrangement may cause a condensation in the ortho position. Thus benzene hydrazodimethylaniline gives, by rearrangement, 2,5,4'-dimethyltriamino diphenyl:



In some cases a rearrangement occurs which gives a derivative of diphenylamine. This is, in some sense, a halfway rearrangement and gives "semidines." Thus p-toluenehydrazodimethylaminobenzene gives, by rearrangement, an orthosemidine:



(Boyd, *J. Chem. Soc.* (*London*), 65, 879).

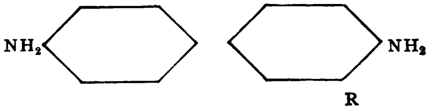
Whether the benzidine or semidine rearrangement shall take place in a given case depends on the nature of the groups present.

As the benzidines are aromatic compounds having two primary amino groups, these may be converted, by nitrous acid, into diazo groups, and the resulting compounds "coupled" with amines or phenols. This gives rise to disazo compounds of the general formula,

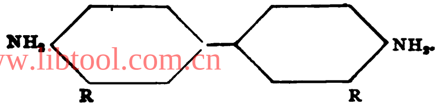
$$X-N=N-C_6H_4-C_6H_4-N=N-Y.$$

These disazo bodies derived from benzidine form the very important group of dyes known as the "congo" series. By varying the substances combined, it has been possible to secure dyes of almost every color. These dyes are "substantive" in character (p. 481).

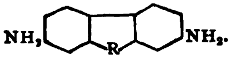
In the study of these dyes the following interesting laws have been discovered. The dyes which are technically valuable are obtained from derivatives of benzidine having substituents in the ortho position to one or both amino groups, that is, of the types,



and



Benzidine derivatives with groups in the meta position have little value for the preparation of dyes unless such a group or groups form a secondary ring, thus:



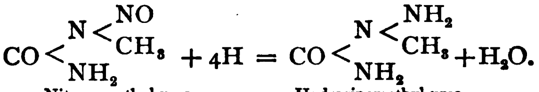
Hydrazobenzene, $C_6H_5NHNHC_6H_5$, is prepared by boiling nitrobenzene with alcohol, sodium hydroxide, and zinc dust. It crystallizes in colorless plates, which melt at 131°. In an alcoholic solution it is rapidly oxidized to azobenzene by the oxygen of the air. Acids transform it into benzidine.

HYDRAZINES.

Hydrazines bear the same relation to *hydrazine*, NH_2-NH_2, as amines bear to ammonia. They are usually prepared by the reduction of nitroso or diazo compounds:

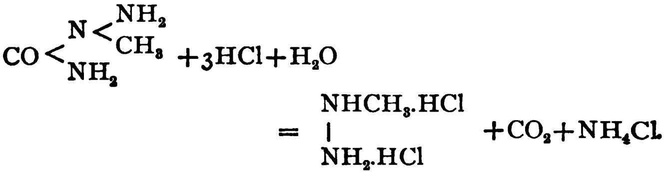
$$(CH_3)_2NNO + 4H = (CH_3)_2N - NH_2 + H_2O.$$

Nitrosodimethylamine. Dimethylhydrazine.



$$CO<\begin{matrix}N<\begin{matrix}NO\\CH_3\end{matrix}\\NH_2\end{matrix} + 4H = CO<\begin{matrix}N<\begin{matrix}NH_2\\CH_3\end{matrix}\\NH_2\end{matrix} + H_2O.$$

Nitrosomethyl urea. Hydrazinemethyl urea.



$$CO<\begin{matrix}N<\begin{matrix}NH_2\\CH_3\end{matrix}\\NH_2\end{matrix} + 3HCl + H_2O = \begin{matrix}NHCH_3.HCl\\|\\NH_2.HCl\end{matrix} + CO_2 + NH_4Cl.$$

Methylhydrazine hydrochloride.

$$C_6H_5N_2Cl + 4H = C_6H_5NHNH_2 \cdot HCl.$$

Phenylhydrazine hydrochloride.

Aromatic hydrazines are also prepared by treating diazonium salts with acid sodium sulphite, and decomposing with hydrochloric acid, the hydrazosulphonic acids which result.

$$C_6H_5N_2Cl + NaHSO_3 = C_6H_5N{=}N-SO_3H + NaCl,$$

Benzene azosulphonic acid.

$$C_6H_5N{=}N-SO_3H + 2H = C_6H_5NH-NHSO_3H,$$

Benzene hydrazosulphonic acid.

$$C_6H_5NHNHSO_3H + HCl + H_2O = C_6H_5NHNH_2HCl + H_2SO_4.$$

Phenylhydrazine hydrochloride.

The aliphatic hydrazines are strong bases, forming two classes of salts, as

$$\begin{array}{l} NHCH_3 \cdot HCl \\ | \\ NH_2 \end{array} \quad \text{and} \quad \begin{array}{l} NHCH_3HCl \\ | \\ NH_2HCl \end{array}.$$

The second molecule of acid is, however, held much less firmly than the first.

The aromatic hydrazines form stable salts only with one molecule of a monobasic acid.

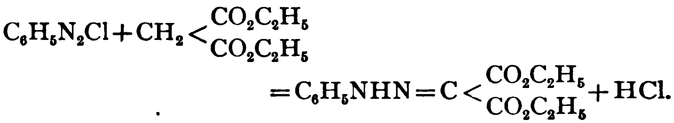
The hydrazines reduce Fehling's solution. In the aromatic series oxidation of hydrazines with cupric sulphate or ferric chloride is occasionally used for the elimination of the amino group, instead of the more usual diazo reaction (p. 459). (Haller, *Ber. d. chem. Ges.* 18, 90, 92, 786.)

Phenylhydrazine, $C_6H_5NHNH_2$, is most easily prepared in small quantities by reducing benzenediazonium chloride with stannous chloride (see above). When pure, phenylhydrazine is a colorless oil, which solidifies at a low temperature, and melts at 24.1°. It boils with slight decomposition at 243.5°, and is best distilled under diminished pressure. It darkens on exposure to the air, and usually has a reddish brown color. It is oxidized by Fehling's solution with formation of aniline, benzene, and phenol. It is a violent poison.

HYDRAZONES, OSAZONES.

The formation of hydrazones from aldehydes and ketones (pp. 179 and 189) has already been mentioned; also the formation of osazones from sugars (p. 364).

Compounds of the type of acetoacetic ester, malonic ester, and 1,3-diketones, containing the group, $-CO-CH_2-CO-$, or the group, $-CH_2-NO_2$, couple with diazo compounds to form hydrazones. Thus malonic ester gives, with benzene diazonium chloride, the hydrazone of mesoxalic acid:

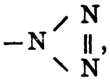


$$C_6H_5N_2Cl + CH_2<\begin{matrix}CO_2C_2H_5\\CO_2C_2H_5\end{matrix} = C_6H_5NHN=C<\begin{matrix}CO_2C_2H_5\\CO_2C_2H_5\end{matrix} + HCl.$$

The reaction is closely analogous to the formation of oximes, from compounds containing the group, $-CO-CH_2-$, when treated with amyl nitrite (p. 201).

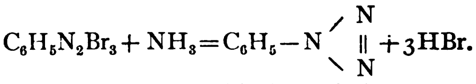
DIAZOIMIDES.

Diazoimides contain the group,



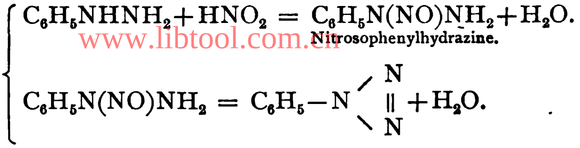
$$-N<\begin{matrix}N\\\Vert\\N\end{matrix},$$

and are prepared by treating diazo perbromides with ammonia, hydrazines with nitrous acid, or diazonium salts with hydrazoic acid.



$$C_6H_5N_2Br_3 + NH_3 = C_6H_5-N<\begin{matrix}N\\\Vert\\N\end{matrix} + 3HBr.$$

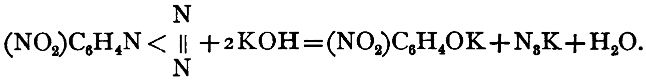
Diazobenzene perbromide. Diazobenzene imide.



$$\left\{\begin{array}{l} C_6H_5NHNH_2+HNO_2 = \underset{\text{Nitrosophenylhydrazine.}}{C_6H_5N(NO)NH_2}+H_2O. \\ C_6H_5N(NO)NH_2 = C_6H_5-N\begin{matrix}\diagup N \\ \| \\ \diagdown N\end{matrix}+H_2O. \end{array}\right.$$

$$(C_6H_5N_2)_2SO_4+\underset{\substack{\text{Hydrazoic}\\ \text{acid.}}}{2N_3H}=\underset{\substack{\text{Diazobenzene}\\ \text{imide.}}}{C_6H_5N_3}+H_2SO_4+2N_2.$$

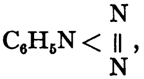
A diazoimide having a nitro group in the ortho or para position can be decomposed by alkalies giving a nitrophenol and a salt of hydrazoic acid:



$$(NO_2)C_6H_4N<\begin{matrix}N\\ \| \\ N\end{matrix}+2KOH=(NO_2)C_6H_4OK+N_3K+H_2O.$$

This reaction, and the last reaction for the preparation of the diazoimides, illustrate the close resemblance between the chemical properties of hydrochloric and hydrazoic acids.

Diazobenzenimide (Triazobenzene, phenyl cyclotriazene),



$$C_6H_5N<\begin{matrix}N\\ \| \\ N\end{matrix},$$

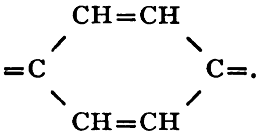
is prepared by treating a solution of benzene diazonium chloride with one-half a molecule of stannous chloride. It is a light yellow oil, which boils at 73.5° under a pressure of 22–24 mm., and has a specific gravity of 1.0853 at 25°. It explodes when distilled under ordinary pressure.

DYES.

A dye is a substance used to give a permanent color to animal or vegetable fibers, and especially to cloth. The dyes which have been longest known are natural substances of vegetable or animal origin, cochineal being, however, almost the only well-known dye-stuff of the latter class. During the last fifty years several of the most valuable natural dyes have been produced artificially. The most important of these are alizarin (p. 212) and indigo (p. 247). In addition to this, new dyes of almost every conceivable color and shade have been prepared, chiefly from coal-tar products. The first commercial dye of this kind was prepared by W. H. Perkin, Sr., in 1857, by the oxidation of an impure aniline sulphate. This led to the popular designation of the dyes as "aniline colors;" and the name still clings to them in common usage, though it is not accurate from a scientific standpoint.

The coal-tar dyes have acquired so great a commercial importance that they have been studied with extreme care, both from the scientific and from the technical standpoint. The special literature devoted to the subject is large,* and only the most elementary principles can be touched upon here.

Chromophore Groups.—It has been found that certain groups almost or quite always give a color to the substances containing them. These are called "chromophore" groups (Witt, *Ber.* 9, 522; 21, 325.) The best known of them are the nitro group, NO_2, the azo group, $-N{=}N-$, and the quinoid group,



Auxochrome Groups. — The presence of a "chromophore" group does not, however, make the substance containing it a

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* See especially Schultz, Chemie des Steinkohlentheers; Nietzki, Chemie der organischen Farbstoffe; Schultz und Julius, Tabellarische Uebersicht der künstlichen organischen Farbstoffe. An English translation of the last has been published by Macmillan and Co.

dyestuff. Thus, azobenzene, $C_6H_5-N=N-C_6H_5$, is deeply colored, but it is not a dye. To make the body a dye it must also contain some acid or basic group which will enable it to combine with the fiber or mordant. These are called "auxochrome" groups. The most important of them are the hydroxyl (phenol) and the amino groups.

Mordants. — It is often necessary to use with a dye some substance known as a "mordant," which shall combine with it, rendering it insoluble, and fixing it in the fiber. For basic dyes, the mordants most often used are tannic acid, with or without some preparation of antimony, and for acid dyes, acetates of aluminium, chromium, or iron. These last are hydrolyzed by water, giving aluminium, chromium or iron hydroxide, which combines with the dye. In some cases the mordant used has an important effect in changing the shade or color produced by the dye (p. 213).

Substantive and Adjective Dyes. — Dyes which will combine with fibers, and color them permanently without the use of a mordant, are said to be "substantive"; those requiring a mordant are called "adjective." "Substantive" dyes for wool and silk are much more often found than for cotton or linen. The "congo" dyes (p. 475) have been mentioned as having special value because they are "substantive" for vegetable fibers.

Other Auxiliary Groups. — Besides the chromophore and auxochrome groups, the presence of other groups in a dyestuff may be important. Thus a sulpho group may render the dye soluble, especially in the form of a salt. In some such cases a solution of the salt is used in the dyeing-vat, and the free sulphonic acid is precipitated in the fiber by the action of acid sodium sulphate. In a somewhat similar manner indigo is sometimes fixed in a fiber by the reduction of o-nitro phenylpropiolic acid with glucose (p. 247), and azo compounds are prepared by treating the fiber successively with their components.

Fast Colors. — Another very important property of dyes is as to whether they are "fast" or not; that is, whether they are permanent when subjected to various kinds of treatment. Thus, dyes are distinguished as "wash-fast," "soap-fast," "alkali-fast," and "light-fast." Dyes which fade rapidly on exposure to the sunlight are called "fugitive." Probably no dye containing a carbon compound is absolutely permanent in the sunlight.

NOTE. — In studying this chapter the student will find it useful to refer to the classification of compounds given in Chapter IX.

Laboratory Exercises.

Preparation of the following compounds:

1. Benzene diazonium chloride (diazobenzene chloride).
2. Aminoazobenzene.
3. Sulphobenzene-azo-α-naphthylamine.
4. Hydrazobenzene.
5. Azobenzene.
6. Benzidine.
7. Phenylhydrazine.
8. Glucosazone.
9. Semicarbazine.

CHAPTER XXII.

SULPHUR COMPOUNDS.

MERCAPTANS OR THIOALCOHOLS.

THE mercaptans may be considered as alcohols in which oxygen has been replaced by sulphur. They have the general formula, R–S–H, and may be prepared from alkyl halides and potassium hydrosulphide, from alcohols and phosphorus pentasulphide, and by the reduction of sulphochlorides:

$$C_2H_5Cl + KSH = C_2H_5SH + KCl.$$

Ethyl mercaptan.

$$C_6H_5SO_2Cl + 6\,H = C_6H_5SH + 2\,H_2O + HCl.$$

Benzene sulphochloride. Thiophenol.

The reaction with phosphorus pentasulphide is complex, and gives poor yields.

The mercaptans are mostly liquids with penetrating and excessively disagreeable odors. As is to be expected from the relation between water and hydrogen sulphide, they have slight acid properties. With mercury, especially, they form well defined salts $(R\text{–}S)_2Hg$, and this fact gives to them their name mercaptan. Nitric acid oxidizes them to sulphonic acids:

$$C_6H_5SH + 3O = C_2H_5SO_2OH.$$

Ethyl mercaptan. Ethyl sulphonic acid.

Ethyl Mercaptan (ethanethiol), C_2H_5SH, is prepared on a large scale from ethyl chloride and potassium hydrosulphide.

It boils at 36.2°, and has a specific gravity of 0.83907 at $\frac{20°}{4°}$. Its odor is so penetrating that it is possible to detect $\frac{1}{460000000}$ mg. by that means, an amount 250 times smaller than the smallest amount of sodium which can be identified by the spectroscope. Ethyl mercaptan is manufactured commercially for use in making "sulfonal" (p. 486). The factory is placed in as secluded a place as possible, but the odor causes trouble at a very considerable distance.

Thiophenol (phenthiol), C_6H_5SH, can be prepared by the reduction of phenylsulphonic chloride (see above). It boils at 172.5°, and has a disagreeable odor. It forms salts with mercury, lead, silver, and other metals, and gives phenyl disulphide $(C_6H_5)_2S_2$ with very mild oxidizing agents.

SULPHIDES OR SULPHUR ETHERS.

The sulphur ethers are prepared by treating metallic sulphides with alkyl halides:

$$2\,C_2H_5I + K_2S = \underset{\text{Ethyl sulphide.}}{(C_2H_5)_2S} + 2\,KI.$$

Mixed sulphides, corresponding to the mixed ethers, can be prepared by treating sodium salts of the mercaptans with alkyl iodides:

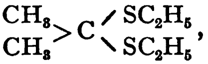
$$C_2H_5SNa + CH_3I = \underset{\text{Ethyl methyl sulphide.}}{C_2H_5-S-CH_3} + NaI.$$

Ethyl Sulphide, $(C_2H_5)_2S$, is prepared from potassium sulphide and ethyl chloride, or by distilling mercury mercaptide:

$$(C_2H_5S)_2Hg = (C_2H_5)_2S + HgS.$$

Ethyl sulphide is insoluble in water, and has a disagreeable odor. It boils at 92°–93°. It is worthy of notice that while ethyl mercaptan has a lower boiling point than alcohol, ethyl sulphide has a very much higher boiling point than ether. These facts are doubtless connected with the association of alcohol to more complex molecules, while ether and ethyl mercaptan do not so associate (Ramsay and Shields, *Zeit. phys. Ch.* 12, 465 and 468).

Acetone Ethylmercaptol (dithioethyldimethylmethane),



$$\begin{matrix} CH_3 \\ CH_3 \end{matrix} > C < \begin{matrix} SC_2H_5 \\ SC_2H_5 \end{matrix},$$

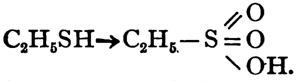
is prepared by passing hydrochloric acid gas into a mixture of acetone and ethyl mercaptan. It is a liquid, boiling with some decomposition at 190°–191° and is manufactured for use in preparing sulfonal (p. 486).

Phenyl Sulphide, $(C_6H_5)_2S$, is prepared by distilling lead thiophenolate,

$$(C_6H_5S)_2Pb = (C_6H_5)_2S + PbS.$$

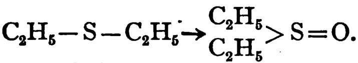
It is a liquid with a disagreeable odor, and boils at 292°–294°.

While oxygen shows only a slight tendency to add elements or groups and assume the quadrivalent form (see *Am. Chem. J.* 27, 311) sulphur exhibits, in a very marked degree, the tendency to become either quadrivalent or sexivalent. As a result of this property of sulphur, the mercaptans may be oxidized to sulphonic acids, the sulphides may be oxidized to sulphoxides and sulphones, and the sulphides and alkyl iodides form sulphonium compounds.



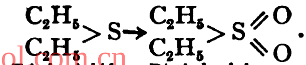
$$C_2H_5SH \rightarrow C_2H_5-S\begin{matrix} /\!\!/ O \\ = O \\ \diagdown OH. \end{matrix}$$

Ethyl mercaptan. Ethyl sulphonic acid.



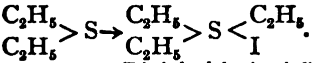
$$C_2H_5-S-C_2H_5 \rightarrow \begin{matrix} C_2H_5 \\ C_2H_5 \end{matrix} > S = O.$$

Ethyl sulphide. Diethyl sulphoxide.



$$\begin{array}{l}C_2H_5\\C_2H_5\end{array}\!>S\rightarrow\begin{array}{l}C_2H_5\\C_2H_5\end{array}\!>S\begin{array}{l}{/\!\!/}O\\{\backslash\!\!\backslash}O\end{array}.$$

Ethyl sulphide. Diethyl sulphone.



$$\begin{array}{l}C_2H_5\\C_2H_5\end{array}\!>S\rightarrow\begin{array}{l}C_2H_5\\C_2H_5\end{array}\!>S<\begin{array}{l}C_2H_5\\I\end{array}.$$

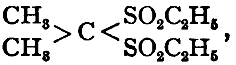
Triethyl sulphonium iodide.

Of these compounds, the sulphones and sulphonium bases will be considered first, as being more closely related to the sulphides.

SULPHONES.

Diethylsulphone $\begin{array}{l}C_2H_5\\C_2H_5\end{array}\!>S\begin{array}{l}{/\!\!/}O\\{\backslash\!\!\backslash}O\end{array}$, is prepared by oxidizing ethyl sulphide $(C_2H_5)_2S$, with fuming nitric acid. It crystallizes in rhombic plates, which melt at 70°, and boil without decomposition at 248°. It dissolves in 6.4 parts of water at 16°. It is neither acid nor basic in its properties.

Diethylsulphone-dimethylmethane (" **sulfonal** "),



$$\begin{array}{l}CH_3\\CH_3\end{array}\!>C<\begin{array}{l}SO_2C_2H_5\\SO_2C_2H_5\end{array},$$

is prepared by oxidizing dithioethyldimethylmethane with potassium permanganate. It melts at 125°–126°, and boils with slight decomposition at 300°. It dissolves in 15 parts of boiling water, or in 500 parts of water at 16°. It is very stable toward either oxidizing or reducing agents. Sulfonal is used as a soporific agent.

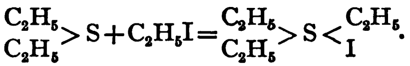
Diphenylsulphone, $(C_6H_5)_2S\begin{array}{l}{/\!\!/}O\\{\backslash\!\!\backslash}O\end{array}$, is formed when benzene is treated with sulphur trioxide, by the oxidation of diphenylsulphide, and by treating benzene sulphochloride, $C_6H_5SO_2Cl$, with benzene and aluminium chloride. It melts at 128°–129°, and boils at 378°. It is decomposed by phosphorus pentachloride, giving chlorbenzene and benzene sulphochloride:

$$(C_6H_5)_2SO_2+PCl_5=C_6H_5Cl+C_6H_5SO_2Cl+PCl_3.$$

SULPHONIUM BASES.

As a nitrogen atom may combine with four alkyl groups, to form a group which unites with hydroxyl, giving a strong base, so a sulphur atom may combine with three alkyl groups and hydroxyl to form a sulphonium base.

Triethyl Sulphonium Iodide. $(C_2H_5)_3SI$, is prepared by treating ethyl suphide with ethyl iodide:

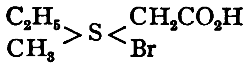


$$\begin{matrix}C_2H_5\\C_2H_5\end{matrix}\!>S+C_2H_5I=\begin{matrix}C_2H_5\\C_2H_5\end{matrix}\!>S<\begin{matrix}C_2H_5\\I\end{matrix}.$$

The iodide crystallizes in rhombic leaflets which are easily soluble. When heated, it decomposes into ethyl sulphide and ethyl iodide, as tetrethyl ammonium iodide decomposes into triethyl amine and ethyl iodide, and as ammonium chloride decomposes into ammonia and hydrochloric acid.

$$(C_2H_5)_3SI=(C_2H_5)_2S+C_2H_5I.$$

When the iodide is treated with silver oxide and water it gives *triethyl sulphonium hydroxide*, $(C_2H_5)_3SOH$, which is easily soluble in water and is a strong base, forming salts readily with acids.



Methylethylthetin Bromide, $\begin{matrix}C_2H_5\\CH_3\end{matrix}\!>S<\begin{matrix}CH_2CO_2H\\Br\end{matrix}$. Alkyl sulphides combine directly with bromacetic acid to form *thetin* compounds of which methylethylthetin bromide is typical. The corresponding bases are weaker than the simple sulphonium bases, because of the acid group which they contain. *Methylethylthetin*, $\genfrac{}{}{0pt}{}{C_2H_5}{CH_3}\!>S<\!\genfrac{}{}{0pt}{}{CH_2CO_2H}{OH}$, has acquired a special interest from the fact that by means of its bromcamphorsulphonate, $\genfrac{}{}{0pt}{}{C_2H_5}{CH_3}\!>S<\!\genfrac{}{}{0pt}{}{CH_2CO_2H}{SO_3-C_{10}H_{14}BrO}$, it has been separated into optically active components (Pope and Peachy, *J. Chem. Soc.* [London] 77, 1072). The asymmetry of the compound must be due to the sulphur atom, and its existence furnishes additional evidence that the four groups are combined directly with the sulphur. A somewhat similar active compound of tin, $\genfrac{}{}{0pt}{}{C_2H_5}{CH_3}\!>Sn<\!\genfrac{}{}{0pt}{}{C_3H_7}{I}$, has also been prepared by the same investigators. The discovery of these active compounds demonstrates that optical activity is not necessarily dependent on the single element carbon.

SULPHONIC ACIDS.

The preparation of sulphonic acids by the oxidation of mercaptans, or sulphur alcohols, has already been referred to. This method of preparation is especially useful in the aliphatic series. In the aromatic series, on the other hand, sulphonic acids are prepared by treating compounds with concentrated sulphuric acid, or, in some cases, with fuming sulphuric acid or sulphur trioxide:

$$C_6H_6 + H_2SO_4 = \underset{\text{Benzene sulphonic acid.}}{C_6H_5SO_2OH} + H_2O.$$

The presence of alkyl groups (as in toluene, $C_6H_5CH_3$, xylene, $C_6H_4(CH_3)_2$, etc.) or of hydroxyl or amino groups, causes aromatic compounds to be more easily attacked by sulphuric acid, and the sulphonic acid derivatives of such bodies may be obtained by the use of concentrated sulphuric acid alone, in many cases. When carboxyl, a nitro group, or a sulphonic acid group is present, the sulphonic radical enters with greater difficulty, and a fuming acid is required.

The position taken by the sulphonic acid group with regard to other groups, in aromatic compounds, is subject to the same rules as those which apply to the nitro group (p. 413).

Structure of the Sulphonic Group. — The structure of the group is established by the following facts:

1. Treatment of salts of sulphonic acids with phosphorus pentachloride gives sulphonic chlorides:

$$\underset{\text{Sodium benzene sulphonate.}}{C_6H_5SO_3Na} + PCl_5 = \underset{\text{Benzene sulphonic chloride.}}{C_6H_5SO_2Cl} + NaCl + POCl_3.$$

This demonstrates the presence of a hydroxyl group in the sulphonic acid, $C_6H_5SO_2OH$.

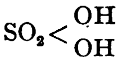
2. Sulphonic chlorides may be reduced to mercaptans, and mercaptans may, in turn, be oxidized to sulphonic acids:

$$\underset{\text{Benzene sulphonic chloride.}}{C_6H_5SO_2Cl} + 6H = \underset{\text{Thiophenol.}}{C_6H_5SH} + HCl + 2H_2O.$$

$$C_6H_5SH + 3O = C_6H_5SO_2OH.$$

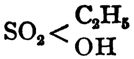
These reactions indicate that the sulphur atom of the sulphonic acid is combined directly with carbon.

If we assume, as seems altogether probable, that sulphuric acid and carbonic acid each contain two hydroxyl groups, the relation of sulphonic acids to sulphuric acid is very closely analogous to the relation of ordinary organic acids to carbonic acid.



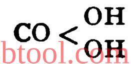
$$SO_2 < \begin{matrix} OH \\ OH \end{matrix}$$

Sulphuric acid.



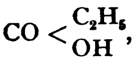
$$SO_2 < \begin{matrix} C_2H_5 \\ OH \end{matrix}$$

Ethyl sulphonic acid.



$$\mathrm{CO}<\begin{matrix}\mathrm{OH}\\ \mathrm{OH}\end{matrix}$$

Carbonic acid.

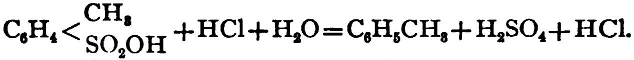


$$\mathrm{CO}<\begin{matrix}\mathrm{C_2H_5}\\ \mathrm{OH}\end{matrix},$$

Propionic acid.

The sulphonic acids are isomeric with the acid esters of sulphurous acid. But while the esters are easily saponified by boiling with water or alkalies, the sulphonic acids are very stable in most cases. They are decomposed by fusion with caustic potash, however, and some of them are decomposed by heating with concentrated hydrochloric or sulphuric acid:

$$C_6H_5SO_2OK + KOH = \underset{\text{Phenol.}}{C_6H_5OH} + K_2SO_3.$$

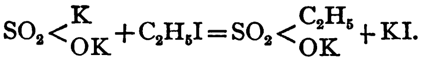


$$\underset{\text{Toluene sulphonic acid.}}{C_6H_4<\begin{matrix}CH_3\\ SO_2OH\end{matrix}} + HCl + H_2O = \underset{\text{Toluene.}}{C_6H_5CH_3} + H_2SO_4 + HCl.$$

The last reaction is often useful for the regeneration of hydrocarbons, or other compounds, from the sulphonic acids.

The sulphonic acids are generally easily soluble in water, are strong acids, and form very stable salts. These facts render the sulphonic acid group very important as an "auxochrome" group in many dyestuffs (p. 480). Sulphonic acids are also important for the preparation of phenols (p. 146), alizarin (p. 212), and "saccharin" (see below).

Ethyl Sulphonic Acid, $C_2H_5SO_2OH$, is prepared by the oxidation of ethyl mercaptan with potassium permanganate. It is also formed by the treatment of potassium sulphite with ethyl iodide. This last reaction is most naturally interpreted by assuming an unsymmetrical structure for the sulphite.



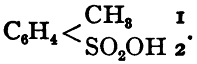
$$SO_2<\begin{matrix}K\\ OK\end{matrix} + C_2H_5I = SO_2<\begin{matrix}C_2H_5\\ OK\end{matrix} + KI.$$

The abnormal reactions of silver nitrite (p. 411) and silver cyanide (p. 306) render such a conclusion somewhat uncertain, however.

Ethyl sulphonic acid forms a deliquescent, crystalline mass. A considerable number of stable salts are known; also the *chloride*, $C_2H_5SO_2Cl$, and the *amide*, $C_2H_5SO_2NH_2$.

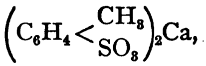
Benzene Sulphonic Acid, $C_6H_5SO_2OH$, is prepared by dissolving benzene in fuming sulphuric acid, or by boiling benzene for some time with concentrated sulphuric acid. The free acid crystallizes in plates containing one molecule of water. It is very easily soluble in water. When its sodium salt is fused with potassium hydroxide, potassium phenolate, C_6H_5OK, is formed. When the same salt is heated with potassium cyanide, phenyl cyanide, C_6H_5CN, distills over..

o-Sulphotoluene,



$$C_6H_4 < \begin{matrix} CH_3 & 1 \\ SO_2OH & 2 \end{matrix} .$$

When toluene is dissolved in concentrated sulphuric acid, a mixture of the ortho and para sulphonic acids is formed. The formation of the ortho acid seems to be favored by carrying on the reaction at a low temperature, but the para acid is always formed in larger amount than the ortho compound. By dilution, and treatment with calcium carbonate, the sulphuric acid forms calcium sulphate, which is difficultly soluble, while the sulphonic acids form calcium toluene sulphonates,



$$\left(C_6H_4 < \begin{matrix} CH_3 \\ SO_3 \end{matrix}\right)_2 Ca,$$

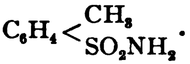
which are easily soluble. After filtering, the calcium may be precipitated by potassium carbonate, leaving potassium sulphonates in solution. By treating the dry potassium salts with phosphorus pentachloride the sulphochlorides are obtained.

$$C_6H_4<\begin{matrix}CH_3\\SO_2OK\end{matrix}+PCl_5=C_6H_4<\begin{matrix}CH_3\\SO_2Cl\end{matrix}+KCl+POCl_3.$$

Toluene sulphochloride.

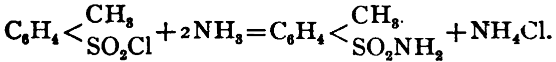
The ortho sulphochloride is liquid at ordinary temperatures, while the para compound is solid, and a partial separation can be based on this fact.

o-Toluene Sulphamide,



$$C_6H_4<\begin{matrix}CH_3\\SO_2NH_2\end{matrix}.$$

When the impure liquid toluene sulphochloride mentioned above is treated with aqua ammonia, a mixture of the ortho and para sulphamides is obtained, from which the latter can be prepared pure by crystallization from water.

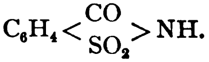


$$C_6H_4<\begin{matrix}CH_3\\SO_2Cl\end{matrix}+2NH_3=C_6H_4<\begin{matrix}CH_3\\SO_2NH_2\end{matrix}+NH_4Cl.$$

Toluene sulphamide.

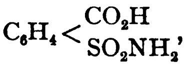
o-Toluene sulphamide crystallizes in octahedra, which melt at 155°.

Benzoic Sulphinide (saccharin),



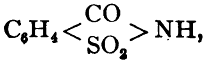
$$C_6H_4<\begin{matrix}CO\\SO_2\end{matrix}>NH.$$

When o-toluene sulphamide is oxidized in a strongly alkaline solution by means of potassium ferricyanide, or potassium permanganate, the *orthosulphamide* of *benzoic acid*,



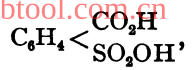
$$C_6H_4<\begin{matrix}CO_2H\\SO_2NH_2\end{matrix},$$

is formed. This melts at 165°–167°, and is not *sweet*. If the oxidation is conducted with potassium permanganate in a neutral or faintly alkaline solution, *benzoic sulphinide*,



$$C_6H_4<\begin{matrix}CO\\SO_2\end{matrix}>NH,$$

is obtained. This is the imide of orthosulphobenzoic acid,



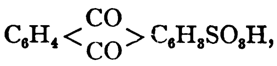
$$C_6H_4<\begin{matrix}CO_2H\\SO_2OH\end{matrix},$$

and is remarkable for its intensely *sweet taste.* The sweetness is variously estimated as being from 300 to 500 times that of cane sugar. It is known commercially as "saccharin," and is manufactured in considerable quantities, partly for the use of patients suffering from diabetes, who are compelled to avoid the use of sugar, partly for use as an adulterant. It has no direct food value, and possesses antiseptic properties which interfere with digestion to some extent. It melts at 220°.

Many other sulphinides are known. They all form well-defined salts in which the hydrogen of the imide group is replaced by metals.

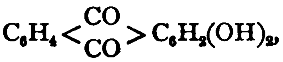
Naphthalene Sulphonic Acids, $C_{10}H_7SO_3H$. Both of the sulphonic acids of naphthalene are formed when naphthalene is dissolved in concentrated sulphuric acid. The formation of the α-acid is favored by a low temperature (80°), while that of the β-acid is favored by a high temperature (160°). The two acids may be separated by means of their lead or calcium salts. By fusion with caustic potash the acids are converted into α- and *β-naphthol,* $C_{10}H_7OH$.

Anthraquinone-2-sulphonic Acid,



$$C_6H_4<\begin{matrix}CO\\CO\end{matrix}>C_6H_3SO_3H,$$

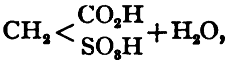
is formed, together with some of the disulphonic acid, when anthraquinone is heated for some time with concentrated sulphuric acid at 250°–260°, or with a slightly fuming acid at 200°–230°. If the cold solution is diluted, and salt is added, the sodium salt of the sulphonic acid is precipitated, a method of separation which can be applied in many other cases. When the sodium salt is fused with potassium or sodium hydroxide, with the addition of some potassium chlorate, alizarin,



$$C_6H_4<\begin{matrix}CO\\CO\end{matrix}>C_6H_2(OH)_2,$$

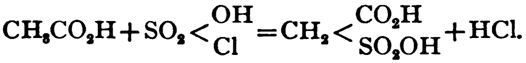
is formed (p. 212).

The Sulphonic Acid of Acetic Acid,



$$CH_2<\begin{matrix}CO_2H\\SO_3H\end{matrix}+H_2O,$$

is prepared by heating glacial acetic acid with the chloride of sulphuric acid :



$$CH_3CO_2H+SO_2<\begin{matrix}OH\\Cl\end{matrix}=CH_2<\begin{matrix}CO_2H\\SO_2OH\end{matrix}+HCl.$$

The acid crystallizes with one molecule of water. It melts at 75°, and forms both acid and neutral salts.

Laboratory Exercises.

Preparation of the following compounds:—

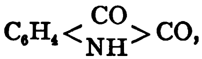
1. Triethyl sulphonium iodide.
2. Benzene sulphochloride.
3. Benzoic sulphinide.
4. Sulphanilic acid.
5. Paranitrobenzoic sulphinide.
6. Paraaminobenzoic sulphinide.

CHAPTER XXIII.

HETEROCYCLIC COMPOUNDS.

Compounds which contain a ring composed of atoms of two or more kinds have been termed *heterocyclic*. A considerable number of such compounds have already received mention. To this class belong the anhydrides and imides of bibasic acids (pp. 277 and 289), lactones (p. 318), pyridine, (p. 437), and quinoline (p. 446), uric acid (p. 293), furfural (p. 360), pyrrol (p. 436), and benzoic sulphinide. A large proportion of those alkaloids whose structure has been more or less completely determined, also have a heterocyclic structure. Some of these will be mentioned briefly in the following chapter. Only a few of the many other heterocyclic compounds require special mention here.

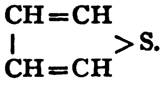
Thiophene, C_4H_4S, and its homologues, thiotolene, $C_4H_8SCH_8$, and 1, 4-thioxene, are found in coal-tar, and are always present in the benzene, toluene, and xylene from that source, unless the latter have been specially purified to remove them. When mixed with a little isatine,



$$C_6H_4<\genfrac{}{}{0pt}{}{CO}{NH}>CO,$$

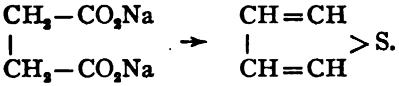
and concentrated sulphuric acid, they give a beautiful blue color. This is called the *indophenin reaction;* and the fact that benzene from coal-tar gives this reaction, while pure benzene from benzoic acid or other sources does not give it, caused Victor Meyer to look for the reason of this difference, and led to the discovery of thiophene (1883) (*Ber. d. chem.*

Ges. 16, 1465). V. Meyer suggested that thiophene is benzene in which the bivalent group $-CH=CH-$ is replaced by a sulphur atom, thus,



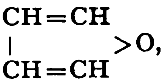
$$\begin{matrix}CH=CH\\ |\\ CH=CH\end{matrix}>S.$$

This view was confirmed when Volhard and Erdmann prepared thiophene synthetically by heating sodium succinate with phosphorus trisulphide (*Ber. d. chem. Ges.* 18, 454).



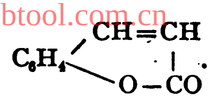
$$\begin{matrix}CH_2-CO_2Na\\ |\\ CH_2-CO_2Na\end{matrix} \rightarrow \begin{matrix}CH=CH\\ |\\ CH=CH\end{matrix}>S.$$

Thiophene boils at 84°, and has a specific gravity of 1.0705 at $\frac{15^\circ}{4^\circ}$. While thiophene is somewhat less stable than benzene, especially toward oxidizing agents, it exhibits a remarkable resemblance to that hydrocarbon in many of its properties and in its derivatives. Chlorine, bromine, and nitro substitution products, sulphonic acids, and carboxylic acids are known in considerable number. The development of the chemistry of thiophene is one of the interesting chapters in the history of organic chemistry, and it can be easily followed in the papers which appeared within a few years after V. Meyer's discovery.

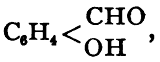


Furfurane, $\begin{matrix}CH=CH\\ |\\ CH=CH\end{matrix}>O$, is formed by distilling barium pyromucate (p. 339). It is also found among the distillation products of pine wood. It is a liquid which is insoluble in water and boils at 32°.

Coumarin,

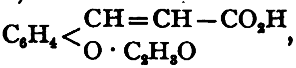


When salicylic aldehyde,



$$C_6H_4<\begin{matrix}CHO\\OH\end{matrix},$$

acetic anhydride, and sodium acetate are heated together *acet-o-coumaric acid,*

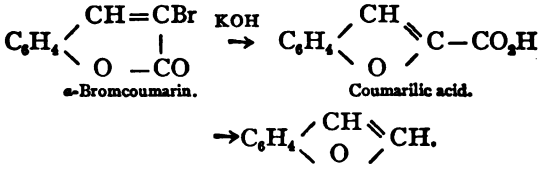


$$C_6H_4<\begin{matrix}CH=CH-CO_2H\\O\cdot C_2H_3O\end{matrix},$$

is formed. This yields coumarin when heated. The synthesis is of especial interest because it was the first application of the well-known and important Perkin's synthesis (p. 244). Coumarin melts at 67°, and boils at 290°. It is found in tonka beans and *Asperula odorata.* It has a pleasant odor, and is used in perfumery for the preparation of the Asperula essence.

Coumarone,

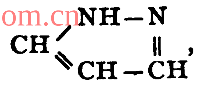
is formed by the action of alcoholic potash upon coumarin dibromide, or upon α-bromcoumarin.



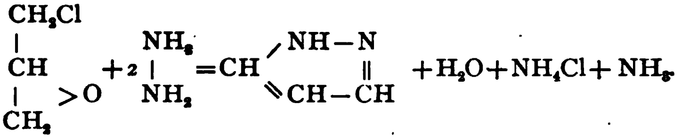
α-Bromcoumarin. Coumarilic acid. Coumarone.

The reaction is evidently somewhat related to the decomposition of β-brom acids when treated with sodium carbonate (p. 393). Coumarone boils at 172°.

Pyrazole,

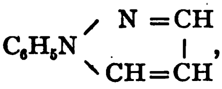


is formed when a mixture of epichlorhydrin and hydrazine hydrate is warmed, at first alone, and then with the addition of zinc chloride, which acts as a condensing agent.



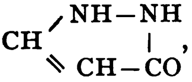
Pyrazole crystallizes in needles, which melt at 70°. It boils at 186–188°. It is easily soluble in water, alcohol, ether, and benzene. The aqueous solution is neutral, but pyrazole forms well-defined salts, of which the chloride, $C_3H_4N_2HCl$, and the chlorplatinate, $(C_3H_4N_2)_2H_2PtCl_6 + 2H_2O$, may be considered as types.

1-Phenylpyrazole,



is formed from phenylhydrazine, $C_6H_5NHNH_2$ and epichlorhydrin. It melts at 11°, and boils at 246.5°.

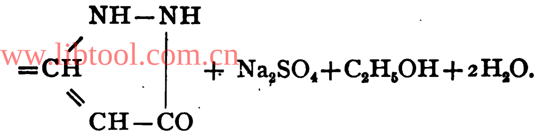
Pyrazolone,



is formed when hydrazine sulphate and sodium formyl acetic ester are warmed with a normal solution of sodium hydroxide.

$$NH_2NH_2H_2SO_4 + H-CO-CHNaCO_2C_2H_5 + NaOH$$

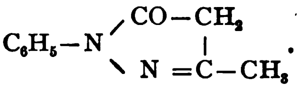
Hydrazine sulphate. Sodium formylacetic ester.



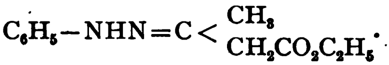
$+ Na_2SO_4 + C_2H_5OH + 2H_2O.$

Pyrazolone crystallizes from toluene in needles which melt at 165°. It is easily soluble in alcohol and water, difficultly soluble in ether. It is not basic in character.

1-Phenyl-3-methylpyrazolone,



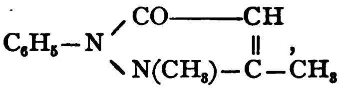
When acetacetic ester and phenylhydrazine are mixed in molecular proportions they condense to a hydrazone,



$$C_6H_5-NHN=C<\begin{matrix}CH_3\\CH_2CO_2C_2H_5\end{matrix}.$$

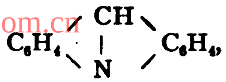
On warming this for some time, it condenses further, with loss of alcohol, forming 1-phenyl-3-methylpyrazolone. This crystallizes from water in prisms which melt at 127°. It boils at 287° under a pressure of 205 mm. Phenyl methylpyrazolone forms salts both with acids and with bases. The silver salt is $AgC_{10}H_9N_2O$, the hydrochloride, $C_{10}H_{10}N_2O \cdot HCl + H_2O$.

1-Phenyl-2,3-dimethylpyrazolone (antipyrine),

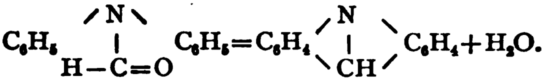


is formed when 1-phenyl-3-methylpyrazolone is heated in a sealed tube to 100°–120° with methyl iodide, caustic potash, and methyl alcohol. Antipyrine crystallizes from toluene in leaflets, which melt at 116°. It is a monacid base. The salts are, mostly, easily soluble in water. Antipyrine is used in medicine as an antipyretic.

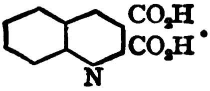
Acridine,



may be considered as anthracene in which a CH group has been replaced by a nitrogen atom. It is formed when formyl diphenyl amine is heated with zinc chloride, or when diphenyl amine is heated with crystallized oxalic acid and zinc chloride:



The reaction is of somewhat more than usual interest, since it indicates very clearly that acridine contains a para union between the nitrogen and carbon atoms of the central nucleus, and, by analogy, points to a similar structure for anthracene. Acridine is also found in coal-tar. It is a very stable substance, melting at 107°, and boiling at a temperature above 360°, without decomposition. It is a weak base. Potassium permanganate oxidizes it to *acridic acid* (2, 3-*quinoline dicarboxylic acid*),



Acridone,  $C_6H_4{<}\substack{CO\\NH}{>}C_6H_4$, may be prepared by the oxidation of acridine with bleaching powder and cobalt nitrate. It is also formed when o-aminobenzophenone,

is heated to 355° with lead oxide. Acridone crystallizes in needles, which melt at 354°. By distilling with zinc dust it is reduced to acridine.

Other heterocyclic compounds in great numbers, and of a great variety of types, are known. Some of those given are no more important than others which might have been selected. It does not seem advisable, however, to extend the list, as it is not possible, in a work of the present scope, to include representatives of all of the types which have been discovered.

Laboratory Exercises.

Preparation of the following compounds:—

1. Thiophene.
2. Antipyrine.

CHAPTER XXIV.

ALKALOIDS.

Many plants contain basic compounds of nitrogen to which the general name *alkaloids* has been given. The plants containing such compounds belong almost exclusively to the class of dicotyledons. In many cases the same plant contains several different alkaloids; but, when this is the case, the different bases are almost invariably closely related in structure. Different plants of the same family often contain the same or closely related alkaloids, while a given alkaloid is rarely found in plants belonging to different families.

Most of the alkaloids exert a powerful physiological action on the animal organism. Many of them are valuable medical agents, and some of them are very powerful poisons.

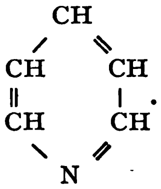
Most of the alkaloids form, with acids, well characterised salts. In many cases they can be extracted from aqueous alkaline solutions by means of immiscible solvents, as ether, amyl alcohol, chloroform, or benzene, while acids, in turn, extract them from solution in such solvents. Many of the alkaloids give, with acids and other reagents, highly characteristic color reactions which are of great value in toxicology. All alkaloids give precipitates with phosphomolybdic and phosphotungstic acids, and many of them, with tannin and with potassium mercuric iodide.

The alkaloids are generally optically active, and are usually laevorotatory.

The number of the alkaloids is very large, and many of them have been carefully studied and their structure established with a good degree of certainty. Only a very few have been prepared synthetically. They are best classified in accordance with the characteristic group which each contains. Only a few of the more important can be mentioned.

1. Pyridine Group.

The alkaloids of this group are derivatives of pyridine,



Pilocarpine, $C_{11}H_{16}N_2O_2$, is the most important alkaloid of Jaborandi leaves (*Pilocarpus pentafolius*). Its chloride is $C_{11}H_{16}N_2O_2 \cdot HCl$. The base somewhat resembles nicotine in its physiological properties.

Coniïne, $C_8H_{17}N$, the alkaloid of hemlock (*Conium maculatum*), has been considered (p. 435), as has also *piperine*, $C_{17}H_{19}NO_3$, the alkaloid of pepper (p. 434). The former is a monacid base, but the latter forms a chlorplatinate of the remarkable formula,

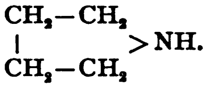
$$(C_{17}H_{19}NO_3)_4 \,.\, H_2PtCl_6.$$

Nicotine ($C_{10}H_{14}N_2$), the principal alkaloid of tobacco (see p. 438), is sixteen times more poisonous than coniïne.

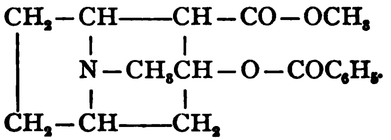
Atropine, $C_{17}H_{23}NO_3$, is the chief alkaloid of the deadly nightshade, *Atropa belladonna*, and is found also in *Datura* *stramonium* and in several other plants. Atropine is a powerful poison. It causes a widening of the pupil of the eye, and is often used by oculists for that purpose. This effect is called *mydriasis*, and is also produced by some other alkaloids, and by some artificial bases. Atropine is a monacid base.

Cocaïne, $C_{17}H_{21}NO_4$, is found in cocoa leaves (*Erythroxolon coca*). It is a monacid base. Cocaïne is much used to produce local anaesthesia for surgical operations upon the eyes or teeth, but it is so poisonous that great care is required in its administration.

According to recent researches, atropine and cocaïne are derivatives, not of pyridine, but of *pyrrolidine*,

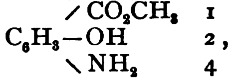


Connection Between Structure and Physiologial Effect of Cocaïne. — The structure assigned to cocaïne is,



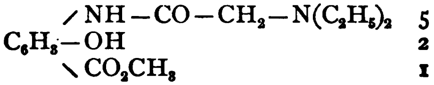
According to this formula, it is an ester of benzoic acid, C_6H_5COOH, and a study of other esters of that acid has led to the conclusion that its peculiar physiological action is dependent largely on that portion of its structure. This has led to the synthesis of two compounds which can replace cocaïne for some purposes of local anaesthesia, but which are far less poisonous than that base. These are:

The *methyl ester of p-amino-o-hydroxy-benzoic acid* ("Orthoform"),



$$C_6H_3\left\{\begin{array}{ll}CO_2CH_3 & 1\\ OH & 2,\\ NH_2 & 4\end{array}\right.$$

and the *methyl ester of diethylglycocoll-aminosalicyclic acid* ("Nirvanine"),



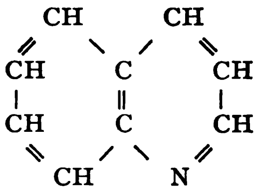
$$C_6H_3\left\{\begin{array}{ll}NH-CO-CH_2-N(C_2H_5)_2 & 5\\ OH & 2\\ CO_2CH_3 & 1\end{array}\right.$$

(Einhorn, *Ann. d. Chem.* (*Liebig*), 311, 26 and 154).

Ecgonine, $C_9H_{15}NO_3+H_2O$, is formed by the saponification of cocaïne, either by dilute acids or by barium hydroxide. The structure is evident from the formula of cocaïne. As an amino-acid it combines both with acids and with bases to form well-characterized salts. Other esters of ecgonine are found along with cocaïne in cocoa-leaves. The ecgonine can be obtained from these by saponification, and can be then converted into cocaïne,—facts of very considerable technical importance.

2. Quinoline Group.

The alkaloids of this group are derivatives of quinoline,



Quinine, $C_{20}H_{24}N_2O_2$, is the most important alkaloid of "Peruvian bark," the bark of several varieties of trees belonging to the genus *Cinchona.* It forms salts with one or with two molecules of a bibasic acid. The former are called the neutral salts, as the latter have an acid reaction. The "neutral" sulphate, $(C_{20}H_{24}N_2O_2)_2H_2SO_4+8H_2O$ (or, crystallized from alcohol, with $2H_2O$), is much used in medicine as an antipyretic. It is a specific in cases of malarial fever.

Cinchonine, $C_{19}H_{22}N_2O$, is usually, if not always, associated with quinine. It possesses similar chemical properties, and has a similar physiological effect.

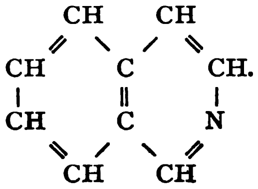
Quinidine, $C_{20}H_{24}N_2O_2$, and *cinchonidine,* $C_{19}H_{22}N_2O_2$, are isomeric with quinine and cinchonine, and can be prepared from them by a molecular rearrangement. They are also found in nature.

Strychnine, $C_{21}H_{22}N_2O_2$, is found in St. Ignatius' bean, in *Strychnos nux vomica,* and in some other plants. Strychnine has an intensely bitter taste. It is a violent poison, 30 milligrams being a fatal dose. In very small doses it acts as a powerful stimulant, in larger doses it produces tetanus.

Brucine, $C_{23}H_{26}N_2O_4$, is always found with strychnine in plants, and is probably closely related to it in structure. It resembles strychnine in its physiological effects, but is a less violent poison.

3. Isoquinoline Group.

The alkaloids of this group are derivatives of isoquinoline,



When incisions are made in the green seed capsules of the white poppy (*Papaver somniferum L*), a milk-like sap exudes, which dries to a gummy mass, and is called *opium*. Opium contains a number of alkaloids, of which the most important, with their average proportion, are the following:

Morphine, $C_{17}H_{19}NO_3+H_2O$	10	per cent
Narcotine, $C_{22}H_{23}NO_7$	6	" "
Papaverine, $C_{20}H_{21}NO_4$	1	" "
Codeïne, $C_{18}H_{21}NO_3$	0.3	" "
Narceïne, $C_{23}H_{27}NO_8+3H_2O$	0.2	" "
Thebaïne, $C_{19}H_{21}NO_3$	0.15	" "

Of these alkaloids only narcotine, papaverine, and narceïne are derivatives of isoquinoline, while morphine, codeïne, and thebaïne are derivatives of phenanthrene.

All of these alkaloids are monacid bases, and all produce a hypnotic effect, though the different individuals vary greatly in power. Morphine and codeïne are most used in medicine.

Laudanum is an alcoholic extract of opium. *Paregoric* is a more dilute extract of opium, containing also camphor.

Hydrastine, $C_{21}H_{21}NO_6$, is the principal alkaloid of golden seal (*Hydrastis Canadensis L.*). It has a strong styptic effect, causing a contraction of the blood-vessels. It is a monacid base.

Berberine, $C_{20}H_{17}NO_4$, is also found in golden seal, and is found in a considerable number of other plants. It crystallizes in yellowish brown needles, and its aqueous solution is yellow, while almost all other pure alkaloids are colorless. It is a monacid base. Berberine has a toxic effect on dogs, producing paresis and interfering with the respiration. Upon men it seems to have little toxic effect, even in considerable doses.

4. ALKALOIDS OF UNKNOWN STRUCTURE.

Veratrine, $C_{37}H_{53}NO_{11}$, is a poisonous alkaloid found in white hellebore (*Veratrum album*), and in sabadilla seeds (*Veratrum sabadilla*).

Jervine, $C_{26}H_{37}NO_{3}$, is found in the same plants, and especially in white hellebore. It also is a violent poison.

Gelsemine, $C_{22}H_{26}N_{2}O_{3}$, is an alkaloid found in the yellow jasmine (*Gelsemium sempervirens*). It is a monacid base. Its poisonous effects resemble those of strychnine in part, and partly those of *curarine*, the alkaloid of "curare," a substance used by the Indians of South America in poisoning their arrows.

Aconitine, $C_{34}H_{47}NO_{11}$, is the alkaloid of aconite (*Aconitum napellus*). It is one of the most violent poisons. In very minute quantity it produces a prickly sensation on the tongue. It widens the pupil of the eye in the same manner as atropine.

Emetine, $C_{30}H_{40}N_{2}O_{5}$, is the chief active principle of ipecac (*Cephaïlio Ipecacuanha*). It is a diacid base. Its emetic effect depends on the local irritation which it causes.

Lobeline, $C_{18}H_{23}NO_{2}$, is found in *Lobelia inflata*. The pure alkaloid is a viscous liquid having a yellow color. As a poison it affects the respiratory organs, inhibiting their action.

Solanine, $C_{52}H_{93}NO_{18}$. See p. 378.

Laboratory Exercises.

Study the general alkaloidal reactions, and the reactions used for the identification of some of the more important alkaloids.

CHAPTER XXV.

COMPOUNDS OF INTEREST IN PHYSIOLOGY AND IN PATHOLOGY.

Proteïns. — This general name is given to a large class of compounds which are most intimately associated with the life processes of plants and animals. All of them except the protamines contain carbon, hydrogen, oxygen and nitrogen; most of them contain sulphur and many, phosphorus. A few contain iron, and copper, chlorine, iodine, manganese and zinc have been found in rare cases.

The percentage composition of the more important proteïns falls within the following limits:

C	50. –55.	Per cent
H	6. – 7.3	“ “
O	19. –24.	“ “
N	15. –19.	“ “
S	0.3– 2.5	“ “

When phosphorus is present it seldom exceeds 0.8 per cent.

For the albumin from the white of an egg the formula $C_{72}H_{112}SO_{22}$ has been given, but the formula cannot be considered as established or important. This formula gives a molecular weight of 1612. Determinations by the freezing-point method have given, approximately, 15,000. Osborne has discussed the question on the basis of the amount and character of the sulphur present, and gives evidence in support of a similar value for the molecular weight. He also assigns definite formula to a considerable number of proteïns (*J. Am. Chem. Soc.* 24, 160).

Classification of Proteïns. — The following classification of the proteïns has been proposed by the American Society of Biological Chemists and the American Physiological Society. (See "Chemical Abstracts," 2, 1286; also "Practical Physiological Chemistry" by P. B. Hawk, p. 86.) A classification based on the structure of the proteïns is not now possible.

I. SIMPLE PROTEÏNS.

- a. **Albumins.**
  Egg albumin, serum albumin, lactalbumin, vegetable albumins.
- b. **Globulins.**
  Serum globulin, egg globulin, edestin, amandin, and other vegetable globulins.
- c. **Glutelins.**
  Glutenin.
- d. **Alcohol-soluble proteïns.**
  Zeïn, gliadin, hordeïn, bynin.
- e. **Albuminoids.**
  Elastin, collagen, keratin.
- f. **Histones.**
  Globin, thymus histone, scombrone.
- g. **Protamines.**
  Salmine, sturine, clupeïne, scombrine.

II. CONJUGATED PROTEÏNS.

- a. **Nucleoproteïns.**
  Cytoglobulin, nucleohistone.
- b. **Glycoproteïns.**
  Mucins and mucoids (osseomucoid, tendomucoid, ichthulin, helicoproteïn).
- c. **Phosphoproteïns.**
  Caseïn, vitellin.
- d. **Haemoglobins.**
  Haemoglobin, haemocyanin.
- e. **Lecithoproteïns.**
  Lecithans, phosphatides.

III. DERIVED PROTEÏNS.

1. Primary Proteïn Derivatives.
    - a. **Proteans.**
        Myosan, edestan.
    - b. **Metaproteïns.**
        Acid metaproteïn (acid albuminate), alkali metaproteïn (alkali albuminate).
    - c. **Coagulated Proteïns.**
2. Secondary Proteïn Derivatives.
    - a. **Proteoses.**
        Protoproteose, deuteroproteose.
    - b. **Peptones.**
        Antipeptone, amphopeptone.
    - c. **Peptides.**

Albumins are soluble in pure water and are not precipitated by a small amount of acid or alkali, apparently because they possess both basic and acid properties. A larger amount of a mineral acid precipitates them, and they are also precipitated by heat when their solutions contain a neutral salt.

Globulins. — These are simple proteïns, insoluble in pure water, but soluble in neutral solutions of salts of strong bases with strong acids. (The precipitation limits with ammonium sulphate should not be made the basis for distinguishing the albumins from the globulins.)

Glutelins are simple proteïns insoluble in all neutral solvents, but readily soluble in very dilute acids and alkalies. They are found in the seeds of cereals.

Alcohol-soluble Proteïns. — These are soluble in alcohol of 70 to 80 per cent as well as in dilute acids and alkalies, but are insoluble in water, absolute alcohol or other neutral solvents. They occur principally in the seeds of cereals: zeïn in maize, gladin in wheat flour, hordeïn in barley, bynin in malt.

Albuminoids have essentially the same composition as other proteïns, but are very insoluble in all neutral solvents. The group includes collagens, keratins, and elastins.

Collagen is a constituent of such forms of connective tissue as tendon, ligament, cartilage, and bone. It is present in maximum amount (31 per cent) in tendon and constitutes the major portion of this form of tissue. The organic portion of bone, the so-called osseïn, is practically identical with collagen.

By boiling with water, especially in the presence of a little acid, collagen is converted into gelatine. Gelatine absorbs cold water and swells up, but does not dissolve. It dissolves in hot water to a colloidal solution, which does not diffuse through parchment, and which solidifies on cooling, if not too dilute.

Keratins form the principal constituent of the epidermis, hair, nails, hoofs, horns, and feathers. They differ from the other albuminoids in containing a large amount of sulphur. A portion of this sulphur is in so loose a state of combination as to give a precipitate of lead sulphide on boiling with an alkaline solution of a lead salt. The keratins are all extremely insoluble and are non-digestible. They give on hydrolysis a larger amount than usual of tyrosine.

Elastin is the principal solid constituent of yellow elastic connective tissue, or ligament, e. g. *ligamentum nuchae.* Elastih resembles keratins and collagen in being insoluble. It differs from keratin in being digestible and in containing only a small amount of sulphur (about 0.14 per cent. Richards and Gies, *Am. J. Physiol*, 7).

Histones are soluble in water but insoluble in very dilute ammonia and, in the absence of ammonium salts, even in an excess of ammonia. They yield precipitates with solutions of other proteïns and are coagulated by heat, but the coagulum is easily soluble in dilute acids.

Protamines are easily soluble, strongly basic polypeptides containing no sulphur. They have been obtained especially from the spermatozoa of eels and fishes. They are not coagulated by heat and form stable salts with strong mineral acids. They precipitate aqueous solutions of other proteïns.

Conjugated proteïns contain the proteïn molecule united with some other molecule or molecules otherwise than as a salt; as with nucleïc acid (nucleo-proteïns), a carbohydrate (glycoproteïns), some as yet undefined phosphorus compound (phosphoproteïns) with haematin (haemoglobin) or with lecithin (p. 433) (lecithoproteïns).

Caseïn is the most important proteïn of milk. Whether the caseïn from different kinds of milk is identical or not has not been fully determined, but the caseïns from different sources differ in some of their properties. The caseïn is coagulated by dilute acids or by the enzyme found in rennet and in the gastric juice. It separates in the form of a calcium salt. When some lactic acid is formed in the milk by the fermentation which naturally occurs in unsterilized milk, the caseïn will coagulate on heating the milk.

Haemoglobin is the chief coloring matter of the blood. It is also the substance which directly absorbs the oxygen of the air in the lungs, combining with it to form oxyhaemoglobin. In the passage from the arterial to the venous system, through the capillaries, in the circulation of the blood, this absorbed oxygen enters into combination with other substances, oxidizing them, and thereby furnishing heat and energy for the body. Haemoglobin contains iron, and both its color and its property of combining with oxygen are supposed to be due to this element.

By means of acids haemoglobin is decomposed into *globin* and *haematin*. The latter is a coloring matter which contains iron, and can be separated in the form of its chloride, which is called *haemin.*

Primary proteïn derivatives are formed, apparently, through hydrolytic changes which involve only slight changes in the molecule. **Proteans** result from the incipient action of water, very dilute acids, or enzymes. **Meta-proteïns** result from the further action of acids or alkalies and are soluble in dilute acids or alkalies, but insoluble in neutral fluids. The substances called "acid proteïns" and "alkali proteïns" are included in the group, but not the salts of proteïns with acids.

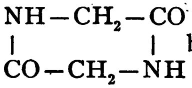
Coagulated proteïns are formed by the action either of heat or alcohol on solutions of proteïns.

Secondary proteïn derivatives result from the further hydrolytic changes of proteïns by acids or enzymes.

Proteoses are soluble in water, are not coagulated by heat, but are precipitated by saturating their solutions with ammonium or zinc sulphate.

Peptones are formed by the action of proteolytic enzymes (pepsin and trypsin, see below) upon albumins, and other proteïns. They have a much smaller molecular weight than the albumins, are easily soluble in water, are not coagulated by heat, and are not precipitated by acids or by potassium ferrocyanide. In the process of digestion they seem to be intermediate between the proteïns of the food and those of the living body, being formed by the decomposition of the former, and, in turn, uniting with themselves, or with other substances, to form the latter.

Peptones are closely related in their properties to the peptides, and the two classes of proteïns are not distinguished from each other by characteristic reactions. The distinction is, for the present, based chiefly on the difference in origin.

Peptides are definite compounds formed by the union of two or more amino acids in such a way that the carboxyl group of one molecule condenses with the amino group of another with the elimination of water. The simplest is glycylglycine, $CH_2NH_2CONHCH_2CO_2H$, which was first obtained from glycine anhydride  $\begin{array}{l} NH-CH_2-CO \\ | \qquad\qquad\quad | \\ CO-CH_2-NH \end{array}$ by hydrolysis with concentrated hydrochloric acid (E. Fischer, *Ber. d. chem. Ges.* 34, 2868). Later (*Ibid.* 37, 2500) the same author showed that by treating glycylglycine with chloracetyl chloride, $ClCH_2COCl$, and sodium hydroxide, chloracetylglycylglycine, $ClCH_2CONHCH_2CONHCH_2CO_2H$, can be prepared. This gives, when treated with ammonia, a tripeptide, di-glycylglycine, $NH_2CH_2CONHCH_2CONHCH_2CO_2H$. In a similar manner tetrapeptides and pentapeptides have been prepared. He points out (*Ber. d. chem. Ges.* 37, 2489) that these synthetic polypeptides resemble the peptones in many of their properties; especially they give the biuret reaction,* give precipitates with phosphotungstic acid, and are hydrolyzed by trypsin.

ENZYMES.

The name enzyme is applied to a class of bodies which are soluble in water, which are not endowed with the capability of propagating themselves, nor with any of the other properties distinctly characteristic of life, and which yet produce many effects closely related to those that are

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* The purplish violet or pinkish violet color produced when equal volumes of a protein solution and a strong solution of potassium hydroxide are treated with 2 to 5 drops of a very dilute solution of copper sulphate.

[illegible] and some other micro-organisms [illegible] organized ferments. The dis- [illegible] the enzyme obtained [illegible] that the so-called [illegible] by means of the [illegible]

[illegible] proteins, but their [illegible] and [illegible] of them as [illegible]

5. **Enzymes which Decompose Amides,** as *urease,* which decomposes urea into carbonic acid and ammonia.

6. **Proteïn-Coagulating,** as *rennin,* found especially in rennet, an infusion of the mucous membrane of the stomach of the calf. It coagulates caseïn.

7. **Enzymes which Form Alcohols,** as *zymase,* an enzyme found in yeast (p. 131).

8. **Deamidizing Enzymes,** such as *adenase,* which converts adenine into hypoxanthine, and guanase, which converts guanine into xanthine.

9. **Oxidizing Enzymes,** such as *xanthooxidase,* which oxidizes xanthine and hypoxanthine to uric acid.

10. A **Uricolytic Enzyme,** which has the property of destroying uric acid, possibly with the formation of urea and glycocoll with allantoin as an intermediate product.

PTOMAÏNES.

When albumin, flesh, or other animal or vegetable nitrogenous substances decay under the influence of bacteria, basic substances called *ptomaïnes* are often formed. Similar compounds seem to be formed in living animals and men during the progress of some diseases caused by pathogenic bacteria, and may play a part in the progress of such diseases.

The study of the ptomaïnes has acquired an especial interest, also, because a number have been discovered which give color reactions resembling some of the reactions of well-known poisonous alkaloids, a fact which has greatly increased the difficulty of the toxicological search for these poisons.

Some of the ptomaïnes are poisonous, others are not. *Neurine* (p. 433) and *Cadaverine* (1, 5-*diaminopentane* (p. 433), have been mentioned. Methyl amine, dimethyl amine, and trimethyl amine have all been found in herring brine.

Tetanine, $C_{13}H_{20}N_2O_4$, is formed when cultures of the bacteria of tetanus, or lockjaw, are made in horse-flesh. It is very poisonous.

Typhotoxine, $C_7H_{17}NO_2$, is obtained in a similar manner with the bacteria of typhoid fever. It is poisonous.

Erysipeline, $C_{11}H_{13}NO_3$, has been found in the urine of persons affected with erysipelas.

The list might be considerably extended.

TOXINS.

In some, and perhaps in most of those diseases which are caused by bacteria, there are generated poisonous compounds which appear to be closely related to the enzymes in their general character. These have been called *toxalbumins* by some authors, while other writers claim that they are not albumins, and prefer the more general name *toxins.* The latter term, in its broader sense, would include poisonous ptomaïnes as well. The poison of serpents, and the two vegetable poisons, *abrin* and *ricin*, which are of a proteïn nature, seem, also, to be closely related to the toxins. Some of these bodies are very virulent. The lethal dose of tetanus toxin has been shown by Brieger and Cohn ("Cellular Toxins," Vaughan and Novy, 4th edition, p. 61) to be 0.0033 of a milligram per kilogram body weight, or 0.00023 gram for a man weighing 70 kilograms, whereas others have determined that $\frac{1}{30}$ of a milligram of ricin per kilogram of body weight is fatal. Such results recall the fact that one part of rennin will coagulate two million parts of caseïn. None of the toxins of this class have been isolated in a pure condition, and the study of their chemical nature is attended with very great difficulty.

ANTITOXINS.

At the same time with the development of toxins under the influence of bacteria the animal organism appears to produce compounds which serve, in some manner which is little understood, as their antidotes. These are called antitoxins. In a few cases, by inoculating animals with a particular disease, a blood serum can, later, be obtained which acts as a specific curative for that disease. The first of the antitoxins prepared in this manner was the antitoxin of tetanus. The one which has, thus far, been most successful, is the antitoxin of diphtheria.

FATS.

From the physiological standpoint, the fats seem to be of value chiefly as a source, or for the storage of energy which can be converted into muscular work or heat. While the fatty acids are among the most stable of organic compounds, and are attacked only by very vigorous agents, the animal organism finds no difficulty, apparently, in securing their complete oxidation to carbon dioxide and water.

INDEX.

An asterisk after the number indicates that the compound is mentioned only in a table.